ELECTRIC TRACTION

ELECTRIC TRACTION

. . BY . .

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PREFATORY NOTE.

Electricity as a motive power for railways is now, of course, well established, and it is more than probable that any new lines where a frequent service is to be provided will be designed primarily for electric traction. There is also the question of electrification of existing railways where the limits of steam working have been reached or local conditions render it economically desirable to make a change. The problem being one in which great interest is evinced, we asked Mr. Lionel Calisch, as an earnest student of the subject, to supply the Great Eastern Railway Magazine with some notes which would be of value, not only to railwaymen but to the general public.

This little book is a reprint of his articles revised and brought up-to-date. It does not pretend to be a text book, but it is hoped that the favour with which the articles have been received in their original form may justify their re-publication.

The Editor,
Great Eastern Railway Magazine.

Liverpool Street,
December, 1913.

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CHAPTER I.

THE substitution of Electric Traction for steam, is, without doubt, the most important question which railways will have to face during the next few years. It is a subject which in recent years has attracted world-wide attention and has been many times fully discussed in the technical papers and before engineering societies.

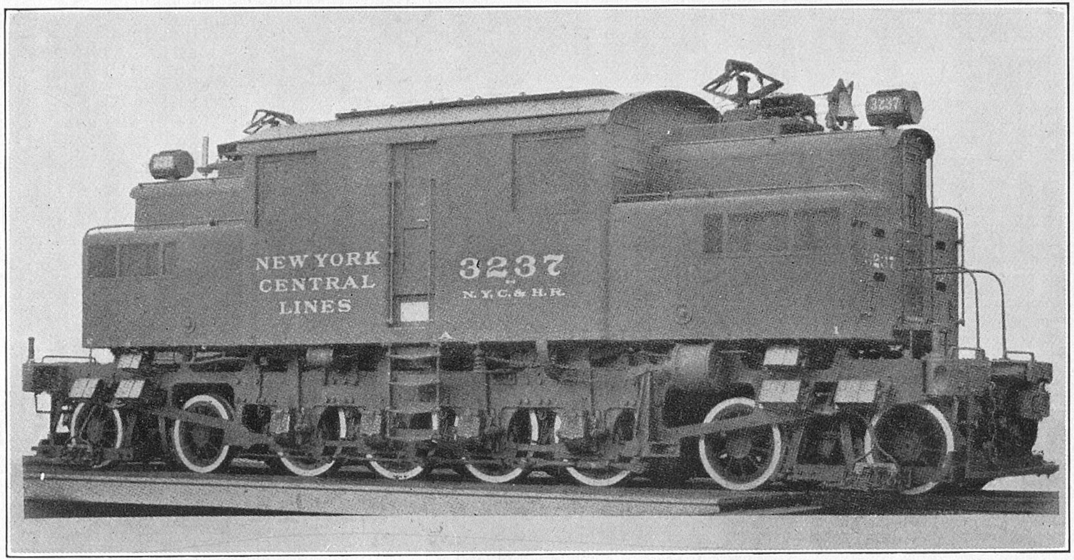
Although in Great Britain comparatively little progress has been made as compared with foreign countries, signs are not wanting that our railways intend to make up lost ground.

While the modern steam locomotive has taken about 80 years to reach its present state of perfection, the electrical industry is barely 30 years old. Yet in this short space of time it has been possible to build electric locomotives, which, in power, speed and performance, eclipse the most powerful steam locomotives of to-day.

In face of these phenomenal developments, it must be obvious that it will be difficult to predict what will happen during the next decade, and it is hoped that a series of articles dealing with this highly important subject may prove of interest to readers of the *Great Eastern Railway Magazine.*

Model electric railways of a very crude kind were devised and shown in operation about 1835, a few years after Faraday's epoch-making experiments on electro-magnetic induction.

The first serious attempt at electric power propulsion on a railway was by a certain Mr. R. Davidson, who constructed in 1842 an electric locomotive which weighed 5 tons and was run at a speed of 4 miles per hour over the Edinburgh and Glasgow Railway. This locomotive was driven by primary batteries (see Mr. Aspinall's presidential address to the Institution of Mechanical Engineers, 1909, Appendix X). So long, however, as the primary



2,200 Horse-Power Electric Locomotive,
New York Central and Hudson River Railroad.

battery was the only available source of electrical energy, no practical results could possibly be obtained.

Between 1860 and 1870 the dynamo electric machine was perfected, and this placed in the hands of experimenters a simple and far more economical means of generating electrical current. Many years were also taken up in experimenting with electric motors.

Although it was known that the dynamo was reversible, and could be used either as generator or motor, it was thought that a motor ought to be designed on different principles, and this led to the waste of much time and money in designing peculiar electro-magnetic machines which did not realise the expectations of the numerous inventors.

The first practical electrical railway was shown at the Industrial Exhibition in Berlin in 1879 by Werner von Siemens. Although it looked like a toy, there were all the essential elements which make up the modern electric railway. Electrical energy was transmitted by means of an insulated rail to the electric locomotive, on which a 3 horse-power motor was mounted which transmitted the power to the axles through bevel and spur wheels.

The ordinary rails were used for the return circuit, and the electric pressure was 150 volts. The speed obtained was 4 miles per hour, and the small locomotive was capable of hauling 3 miniature trailers.

This demonstration was repeated at Brussels and Düsseldorf, and also at Frankfurt in 1881.

This was followed in 1883 by the construction of the well-known Portrush—Bushmill's line in Ireland, which is about 6 miles long and is still at work today. The third rail is used to transmit the electric power to the train, with return through the track rails, while the speed on the level is 12 miles per hour.

It is not proposed to go any further into historical details as this would take up far too much space, but before leaving this subject mention must be made of the Liverpool Overhead Railway which was opened in 1893. The chief point of interest in connection with this line at the time was the use of electric traction under conditions where steam traction would have been quite practicable.

Attention must also be drawn to the work done by Mr. Frank J. Sprague on multiple unit control, which was first put into systematic use in 1898 when it was adopted by the South-side Elevated Railroad of Chicago. This work was of the greatest importance in the history of electric traction, for it gave the electric train enormous advantages over a steam train, as will be shown later on. The first English railway to use multiple unit control was the Great Northern and City Railway in 1904, very shortly followed by the Central London Railway, where the existing electric locomotives were superseded by motor cars coupled on the multiple unit system.

Probably the two paramount questions in the minds of steam railway men in connection with this problem are :—

(1.) What advantages can be obtained by adopting electric traction ?
(2.) What will it cost to instal the new system, and to operate and maintain it ?

These questions will be dealt with in the last chapter.

We will now briefly summarise the various classes of railway service and note the characteristics of each.

Railway traffic may be broadly divided into five groups :—

(1.) Main Line Passenger Traffic. The characteristics of this class of service are high speed, few stops, and a comparatively infrequent service—perhaps not more than one or two trains per hour.
(2.) Suburban and Inter-urban Traffic. That is,

lines leading from suburbs into cities, or between two cities not far apart, carrying business people to and fro.

The characteristics of this class of service are frequent stops, a very heavy service at busy hours, and the necessity to run at fairly high speeds in the case of non-stop trains.

(3.) Urban Traffic on Overhead and Underground railways in large cities. The characteristics are a very heavy service, frequent stops and moderate speeds.

(4.) Country Branch Line Traffic. The service is very light (on several lines there is only one train in, say, two hours) and, as a rule, the speed is not very high. On many railways this class of service is handled entirely by rail motor cars.

(5.) Goods Traffic.

At present there is but little probability that, in this country, for long distance main line traffic the steam locomotive will be superseded, and considering the matter from the point of view of the travelling public it must be admitted that the passengers could not expect a very great advantage. The air of some tunnels would be purer, and a short time would be saved in starts and stops, but no considerable saving of time could be made without increasing the maximum speed of the train. It is true that this maximum speed can be more easily and safely increased with electric than steam traction, and we hear already of proposals to run an electric train service between London and Brighton in 45 minutes, which means a maximum running speed of about 75 miles per hour. It is doubtful, however, if it will pay to provide such high speeds, especially as tramways and motor-buses cannot compete with long distance trains; and unless there be some good local reasons, such as an extremely heavy service, heavy grades, or long tunnels in which smoke would be a nuisance, railways would gain practically nothing by a change in motive power. Moreover, the steam locomotive on main lines is working under its most efficient conditions, while the introduction of superheating and feed water heating has resulted in greater economy. Superheating is advantageous on long, steady runs, but the advantage is small for runs with frequent stops.

Experience has already shown that electric traction is superior to steam on elevated and underground railways in large cities, and from this class of service (No. 3) the steam locomotive has almost entirely disappeared. We have seen already that the characteristics of this class of traffic are a very heavy service, frequent stops, and moderate speeds, and these do not differ much from the characteristics of a suburban and inter-urban service.

Probably one of the chief reasons which prompted railway companies in the past to instal electric traction on elevated and underground railways was on account of its cleanliness and the absence of smoke and dirt. It is clear that the steam locomotive would be entirely unsuitable for hauling trains in the tubes which now play such a very important part in dealing with the traffic requirements of London. It is extremely probable that, if it had not been for this feature of cleanliness, a much longer time would have elapsed before the attention of railway companies would have been drawn to the great advantages of electric traction. It was, however, found that, after all, cleanliness was only a minor advantage. Wherever electric traction has superseded steam on elevated and underground lines the train service has practically been doubled and the speed increased about 30 to 40 per cent.—results which could never be economically obtained with steam.

CHAPTER II.

PROBABLY the greatest advantage possessed by electric traction is the possibility of employing high acceleration, whereby an electric train can attain a high rate of speed in a very short time. Acceleration is defined as the rate of change of speed relative to time, and is usually expressed in feet per second per second, or in miles per hour per second. An acceleration of 1 mile per hour per second means that in each second the speed is increasd by 1 mile per hour.

With electric traction the usual acceleration obtained in practice is about 1·0 to 1·3 miles per hour per second, so that in 30 seconds a train would attain a speed of from 30 to 39 miles per hour, while with the ordinary steam train one can only obtain an average acceleration of about 0·4 to 0·5 mile per hour per second, although the well-known " Decapod " designed by Mr. James Holden achieved an acceleration of nearly 1·1 miles per hour per second.

To perform a given run a train has to go through the process of acceleration up to a particular speed, then go through a period of running at an approximately constant speed, and finally through a period of retardation while the brakes are applied. The higher acceleration attained is generally accompanied by a greater retardation—that is, an electric train can be brought to rest when running at a high speed in a shorter time than a steam train, owing to the installation of the latest type of high speed passenger brakes, large air reservoirs and high capacity pumps. The usual deceleration with steam trains is 1·25 to 1·60 miles per hour per second, while with electric traction about 1·5 to 2 miles per hour per second is generally made. The rate of retardation depends chiefly on the type of braking equipment, and is not in any way affected by the form of traction adopted.

It will be seen, therefore, that for short distances the average speed from start to stop is chiefly governed by the acceleration.

In figure No. 1 speed-time diagrams are given of both electric and steam trains, each performing a run of 0·7 miles, which represents an average distance between suburban stations such as is found on many suburban lines.

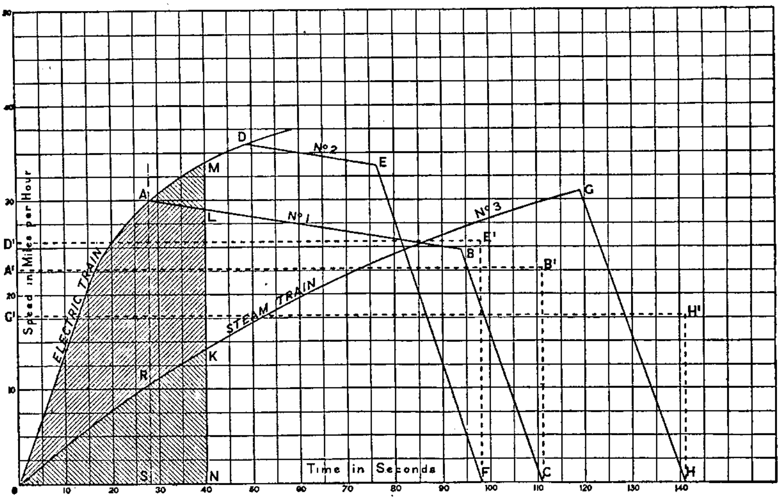


FIG. 1.

Two runs are shown for the electric train. In the first run the electric train attains a speed of 30 miles per hour in 28 seconds; power is then cut off, and the train is allowed to drift or coast for 66 seconds, the speed dropping (due to friction) to about 24·7 miles per hour; the brakes are then applied, the train having covered the distance in 111 seconds.

In the second run the electric train is allowed to attain a speed of 36 miles per hour before power is cut off; the coasting period is now reduced to 28·5 seconds, the speed falling to 33·7 miles per hour; the brakes are then applied, the total distance being covered in 98·5 seconds.

The steam train is accelerating all the time, and only reaches a speed of 31 miles per hour in 119 seconds from the start, when the brakes are applied. This may be regarded as an average performance such as is obtained with steam locomotives on suburban railways.

We can now compile the following figures obtained from figure No. 1 :—

	ELECTRIC TRAIN.		STEAM TRAIN.
	Run No. 1	Run No. 2	
Time from start to stop in seconds..	111	98·5	141
Distance covered in miles	0·7	0·7	0·7
Average speed from start to stop in miles per hour	22·7	25·6	17·9
Maximum speed in miles per hour..	30	36	31

It can easily be shown that the area of a speed-time diagram is equal to the distance passed over. This area may be found either by measurement with a planimeter, or else by obtaining the average height of the diagram and multiplying it by the base. Let us consider the speed-time diagram O A B C which represents the run of electric train No. 1. If we take the average height of the diagram, we obtain the average speed, while the base represents the time taken for the run. If we therefore draw a rectangle with the average speed as height and the time taken to cover the distance as base, the area of the rectangle represents the distance passed over. In figure No. 1 the three rectangles are drawn in dotted lines, each having an area equal to that of its respective speed-time diagram. As the time is taken in seconds, and the speed in miles per hour, it is necessary, in order to get the correct figure, to convert the speed into miles per second.

We obtain therefore :—

$$\text{Area of rectangle No. 1} = \frac{22{\cdot}7}{3600} \times 111 = 0{\cdot}7$$

$$\text{,,} \quad \text{,,} \quad \text{No. 2} = \frac{25{\cdot}6}{3600} \times 98{\cdot}5 = 0{\cdot}7$$

$$\text{,,} \quad \text{,,} \quad \text{No. 3} = \frac{17{\cdot}9}{3600} \times 141 = 0{\cdot}7$$

It will be seen that the areas of the three rectangles are the same in each case and consequently the distance passed over, which it will be remembered was 0·7 mile in each case.

Several interesting deductions can be made from the speed-time diagrams in figure No. 1. The most important fact is that it shows clearly the superior acceleration obtained with electric traction.

It will be noticed that the line O A is much steeper than O K, and also that both lines are practically straight during the early part of the acceleration period, but afterwards curve considerably.

In the speed-time diagram the average acceleration up to any instant is given by the slope of the line, the slope being the ratio of the vertical and horizontal distances, both of which are measured in the right units. For instance :—the average acceleration during the first 28 seconds for the electric train is $\frac{AS}{OS} = \frac{30}{28} = 1{\cdot}07$ miles per hour per second, and for the steam train $\frac{RS}{OS} = \frac{11{\cdot}2}{28} = 0{\cdot}4$ miles per hour per second.

Also the speed-time diagrams are useful in ascertaining the distance passed over during any length of time.

Referring again to figure No. 1—the distance passed over during the first 40 seconds is represented by the following areas :—

For the steam train—distance passed over=area O K N.

For electric train No. 1—distance passed over=area O K N +area O A L K=area O A L N.

For electric train No. 2—distance passed over=area O K N +area O A L K+area A M L=area O A M N.

Electric train No. 1 has therefore covered a considerably greater distance in the same period than the steam train, and this distance is represented by the area O A L K.

Electric train No. 2 has travelled in the same time a distance which exceeds that of the steam train by the amount represented by area O A L K and area A M L, while electric train No. 2 has exceeded the distance covered by electric train No. 1 by the amount represented by area A M L.

The above areas have been measured with a planimeter and the following results have been obtained:—

Area O K N	represents	a distance	of	443 ft.
Area O A L K	,,	,,	,,	800 ft.
Area A M L	,,	,,	,,	46 ft.

Therefore in the first 40 seconds the following distances have been covered:—

By the steam train—443 ft.
By electric train (No. 1)— 443+800=1243 ft.
By electric train (No. 2)—1243+ 46=1289 ft.

The distances covered at any instant during the run can thus be found, and in figure No. 2 the results have been plotted as vertical ordinates against time. The vertical distance at any point along the curves will give the position of each train at any instant. These curves show clearly the much greater distance which the electric trains cover during the period of acceleration.

We see, therefore, that without even increasing the maximum speed we can obtain an increase of about 26 per cent. in the average speed from start to stop. This, however, is a somewhat different thing from what is known as the schedule speed. The latter term takes into account the time occupied at station stops, and is therefore a somewhat lower figure than the former.

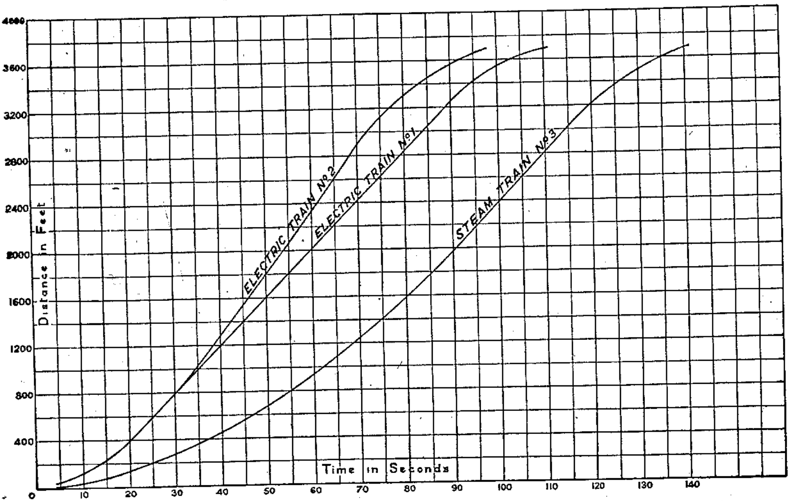


Fig. 2.

It can easily be shown that with one stop per mile (taking the duration of each stop to be 20 seconds) it is only possible to obtain a schedule speed of some 17 miles per hour when an acceleration of 0·4 miles per hour per second is used, but, by increasing the acceleration up to 1 mile per hour per second, a schedule speed of 26 miles per hour may be obtained.

On railways where electric traction has been introduced the schedule speed has been greatly increased as shown in the following table :—

Railway.	Schedule Speed in Miles per hour.		Percentage Increase.
	Steam.	Electric.	
Lancashire and Yorkshire	20	30	50%
Mersey	15·6	19·9	27·5%
London, Brighton and South Coast (London Bridge—Victoria).. ..	14·8	21·6	46%
Manhattan Elevated (New York) ..	11·5	15·8	37%
North Eastern	16·7	20·0	20%
Inner Circle	11·2	15·7	40%

Acceleration is produced by the application of a force. The relation between acceleration A, force F and weight W is expressed by the formula $F = \frac{W}{g} \times A$, where g is the acceleration due to gravity and is equal to 21·9 miles per hour per second.

Therefore, in order to accelerate a train at the rate of 1 mile per hour per second, a force is required equal to $\frac{2240}{21 \cdot 9} = 102 \cdot 3$ ℔. per ton ; but in practice a round figure of 100 ℔. per ton is taken. In order to accelerate a train a sufficient force or tractive effort must be provided to overcome the various forces opposing motion. The tractive effort required depends upon (1) The rate of acceleration ; (2) The gradient which may either resist or assist the tractive effort ; (3) The train resistance ; and (4) The weight of train to be hauled. The train resistance varies with the speed, but depends at the same time on so many other varying conditions that it is near enough for estimating purposes to assume a constant resistance of 12 ℔. per ton.

Suppose we wish to accelerate a train at the rate of 1 mile per hour per second we should require a tractive effort of 112 ℔. per ton, 100 ℔. for acceleration and 12 ℔. for overcoming train resistance, assuming of course that the train is on the level.

In a steam locomotive the power is limited to that of the boiler which the locomotive carries, and this is limited in size by the construction gauge. There is no such limitation as regards power in the electric locomotive or train, for it obtains its power from a central power station and can therefore exert an almost unlimited tractive effort.

Electric motors are able to maintain the high tractive effort exerted at starting at nearly constant value during the greater part of the accelerating period and until very nearly the maximum journey speed has been attained. A steam locomotive is only able to exert its maximum tractive effort until a speed of some 4 or 5 miles per hour has been reached, after which it decreases very rapidly with increasing speed.

The chief reasons why a much higher acceleration can be obtained with electric traction are therefore briefly as follows :—

1st — Because an unlimited supply of power is available at starting.

2nd—The turning effort of an electric motor is uniform and not of a pulsating character as in a steam locomotive.

3rd—Slipping of driving wheels is almost entirely avoided owing to the fact that more driving axles are employed, and consequently a large proportion of the total train weight can be utilized for the purposes of adhesion.

Steam traction for high speed suburban traffic has reached its limit, and any attempt to run with steam trains a high schedule speed, such as is obtained with electric trains, results in very much increased fuel and maintenance costs.

A striking example was mentioned by Mr. Aspinall in his presidential address to the Institution of Mechanical Engineers in 1909. Mr. Aspinall says, referring to the electrification of the Lancashire and Yorkshire railway between Liverpool and Southport :

> " During the transition stage from steam to electrical working, there came a period when it was necessary to run steam trains in between electrical trains at the same speed in order to keep them out of the way of the latter. This afforded an opportunity of comparing the coal consumption of the locomotives and the power house, and it was found that the six wheeled coupled tank engines, which did the work in 1904, consumed 80 lb. of coal per train mile with express trains, and 100 lb. with

> stopping trains. This excessive locomotive consumption was due to the high acceleration required. The consumption of coal at the power station in 1908 works out to 49 lb. per train mile for the electrical trains."

Perhaps it may prove of interest to indicate briefly how to estimate the horse-power capacity required for a train. We have already seen that in order to accelerate a train at the rate of 1 mile per hour per second a tractive effort of 112 lb. per ton on the level is required. Suppose the train weighs 150 tons, then the tractive effort required would be $150 \times 112 = 16{,}800$ lb. If the tractive effort was kept uniform until a speed of 20 miles per hour was reached, the maximum power exerted by the motors would occur at that speed and would be at the rate of

$$\frac{20 \times 5280}{60} \times 16{,}800 = 29{,}568{,}000 \text{ foot lb. per minute,}$$

or $\frac{29{,}568{,}000}{33{,}000}$* $= 896$ horsepower. In such a train probably 8 125-horsepower motors would be installed.

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* 1 horsepower = 33,000 foot lb. per minute.

CHAPTER III.

We will now proceed to consider the technical features of the three systems of electric traction now in use, viz.—Direct Current, Single Phase Alternating Current; and Three-Phase Alternating Current.

Take first the Direct Current or "D.C." system. With this system the motors on the train are supplied with direct current from a 3rd rail or overhead conductor at a pressure of about 600 volts. The 3rd rail is used in cases of heavy traffic, while the overhead trolley is adopted on railways having a comparatively light service or where the direct current is used at a higher pressure than 600 volts. During the last few years several of the inter-urban roads in America have adopted a D.C. pressure of 1200 volts and even 2400 volts, while the Central California Traction Company has a protected 3rd rail system using 1200 volts D.C. In London we have become so accustomed to see a 3rd and 4th rail that it may surprise some readers to hear that the 4th rail is really not necessary. The 4th rail takes the place of the track rails which would otherwise be used for the return circuit, but owing to Board of Trade requirements in regard to voltage drop, and also due to the fact that track rails are used for automatic signalling, it was on some railways considered advisable to adopt an insulated rail for the return circuit. Among the railways in London not using a 4th rail may be mentioned the Central London, while in America there is not a single railway using an insulated rail for the return circuit. In the case of very short lines, where the pressure drop can be kept within reasonable limits, direct current is generated in a power house at the voltage required by the motors without the interposition of any transforming plant. As examples of this simple system we may mention the Liverpool Overhead, Mersey, and Great Northern and City

Railways. When, however, the distances become more than about 3 miles the pressure drop between power house and train with the direct feed becomes too great and a different method of power transmission must be employed. The usual arrangement is to generate in a power house 3-phase alternating currents at high pressure (generally 6000 or 12000 volts) and to transmit this energy to transforming sub-stations placed at suitable intervals along the line.

The sub-stations usually contain the following apparatus :—

(1.) Static transformers for transforming the high pressure 3-phase alternating current received from the power house to low pressure 3-phase alternating current.

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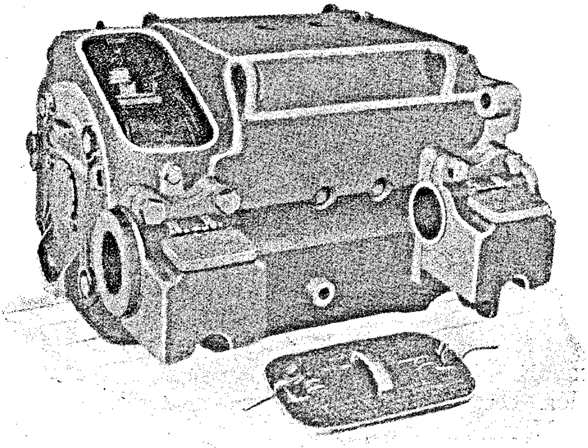
(2.) Rotary converters or motor generators—usually the former—which receive the low pressure 3-phase alternating current and convert it into 600 volt direct current.

The direct current obtained from the rotary converters or motor generators after being passed through suitable switchgear is fed direct into the 3rd rail.

The system of distribution above described is used in practically all large direct current electrifications throughout the world, and the system in this country is exemplified on the Metropolitan, Central London, London Underground Tubes, Lancashire and Yorkshire, North Eastern, etc.

The essential principle underlying all electric motors and practically all electric apparatus is the law of electro-magnetic induction (first thoroughly expounded by Faraday). It is this : when an electric current is passed through a conductor it creates a magnetic force in the space surrounding that conductor ; and, conversely, when a conductor is passed through a magnetic field of force an electric current is produced in that conductor. This interaction is made more effective by forming the conductor into a coil of many turns which multiplies the effect, and by the use of iron which strengthens the magnetic field.

All dynamos and motors consist, broadly speaking, of coils of wire and magnetic fields moving relatively to each other. The currents produced in the coils of all dynamos are what are known as alternating currents—that is, they reverse several times per second and form a succession of waves. In continuous or direct current machines these currents are sifted, by means of a device known as "the commutator," into a practically uniform flow in one direction.

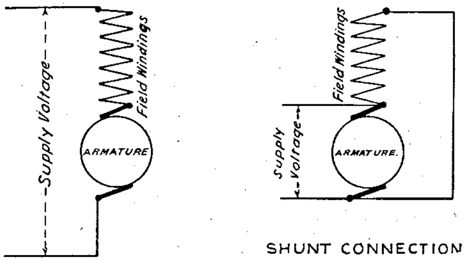


125 Horsepower D.C. Motor.

Direct current motors consist essentially of two parts. The fixed element provides the magnetic field, and the rotating part, called the "armature," contains the conductors which cut the lines of force of the magnetic field.

The "torque" or turning moment of a motor depends upon the strength of the magnetic field and the amount of current passing through the armature. When the armature is revolving in a magnetic field, however, it opposes the passage of the current with a counter electro-motive force, which is proportional to the speed of rotation and the magnetic field.

In electric motors the magnetic field is produced by the electric current supplied; and the field magnets may be either series or shunt wound—that is to say the whole current supplied may pass through the field magnets and armatures in series, or it may be divided between the field magnets and armature in parallel as shown in Fig. 3.



SHUNT CONNECTION

SERIES CONNECTION

Diagram illustrating Series and Shunt Wound Motors.

FIG. 3.

In electric traction only series motors are used: first because they give the greatest torque at starting, and secondly because their speed varies with the tractive effort exerted. At the moment of starting there is no counter electro-motive force, and, if the full electro-motive force were applied, the motor would be damaged by the heavy current. The greatest turning effort is required from the motor at the moment of starting, and this means that the current has to be greater during acceleration than at other times.

The series motor automatically adjusts its speed in accordance with the load, running more slowly if the weight of the train be greater. The speed with a given load, however, is definite ; it is dependent upon the voltage applied to the motor. The speed can be reduced by inserting a resistance in the motor circuit, but this is done as a temporary expedient only. In Fig. No. 4 a curve is drawn shewing how the speed of a series motor varies with the load.

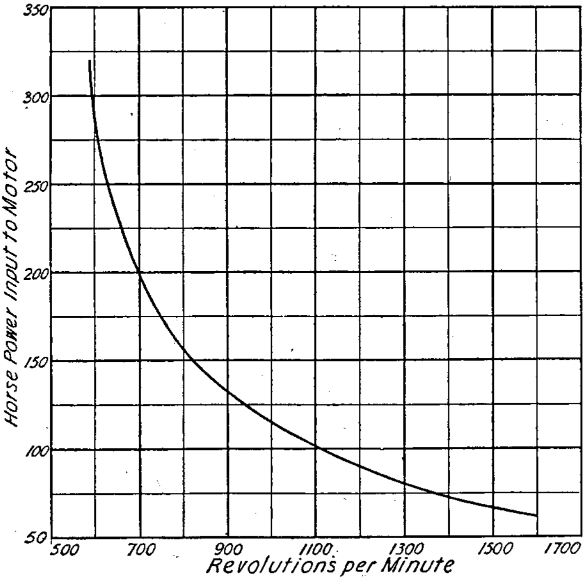

Curve shewing relation between Speed & Load of a 225 H.P. Direct-Current Traction Motor for a constant electric supply pressure.

FIG. 4.

In order to minimise the waste of energy which takes place in the external resistances at starting the series-parallel motor connection is used. It is briefly thus : If two motors are run in series, their counter electro-motive forces are added to oppose the supply pressure, and this means that less voltage is taken up by the external resistances. When the full supply voltage is applied to the two motors in series, after the resistance has been cut out, the speed of each motor is exactly half of that obtained with the motors in parallel. With a two-motor equipment the operation in practice is briefly as shewn in Fig. No. 5. At starting, the two motors and the entire external resistance are in series across the supply voltage as shown in No. I. The resistance is then gradually cut out, generally in four steps, until No. II. position is reached, when the motors are in series without any resistance in at all. This gives one running position, and the speed is exactly half of the maximum speed of the motors. The motors are then thrown in

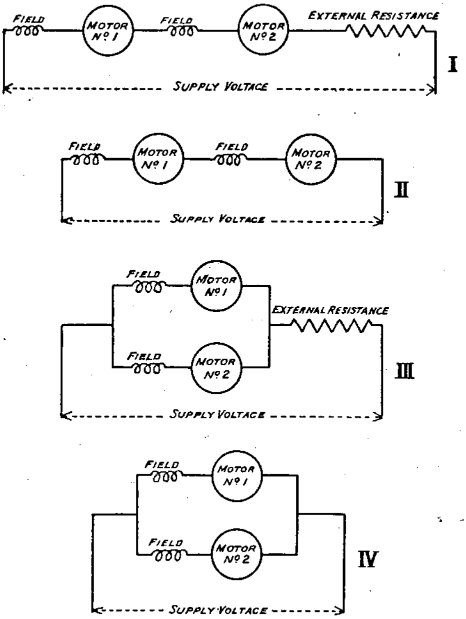


Diagram showing Series-Parallel Motor Connections.

FIG. 5.

parallel with the external resistance in again, as shown in No. III., and the resistance is again cut out in about four steps until No. IV. is reached, when the motors are both receiving their full voltage and are running at full speed. The series-parallel connection considerably increases the efficiency during starting, since the losses in the external resistance during starting would be much greater were the motors in parallel from the start, and the total current supplied to the train while the motors are in series is half of that supplied when the motors are in parallel.

In order to reverse the direction of motion in a motor it is necessary to reverse the direction of the current, either in the field magnet or armature, for reversing the current supplied to a motor as a whole has no effect upon the direction of rotation.

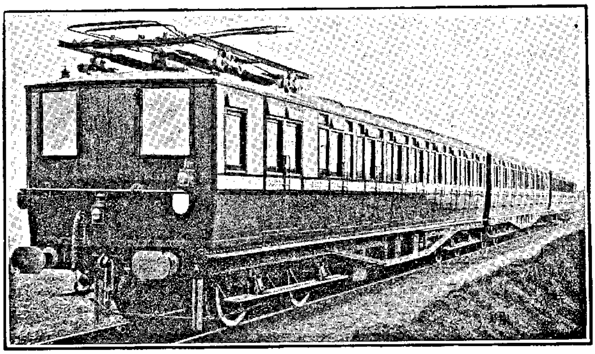
Perhaps it will be well to say a few words about transformers and rotary converters as used in the sub-stations. The transformer, which is used for altering the voltage of the supply, plays an important part in the electrical industry, and is a very simple and effective piece of apparatus. It consists essentially of two coils, one for the high pressure and one for the low pressure current, wound on a core of soft laminated iron. An alternating current is applied to one of the coils, called the "primary," and this produces in the iron core a magnetic field reversing its polarity with each alternation of the current. According to Faraday's law, these changes in the magnetic field induce a current in the other coil, or "secondary" as it is called. The voltage in each coil is proportional to the number of turns, and any desired voltage transformation can be obtained by adjusting the number of turns on the coils. The loss of energy in a transformer is very small as there are no rotating parts involving friction at bearings, but there is a constant loss in the iron caused by the changes of magnetic field. The efficiency of a well designed transformer at full load is generally as high as 98 per cent.

The rotary converter, used for converting alternating to direct current, may be looked upon as a direct current dynamo machine, having points in the armature windings connected to a set of contact rings. Continuous connection can thus be made with each point from the outside while the armature is revolving. The number of points corresponds with the number of different phases of current for which the machine is intended, and they are spaced at equal distances apart. The most general arrangement for traction work is a 6-phase current, derived from a 3-phase current by keeping each phase entirely separate in the secondary circuits from the transformers. These machines are generally started up from the direct-current side or very often by means of a small 3-phase motor from the 3-phase side. They are highly efficient and very reliable.

With direct-current supply for railway trains, a battery of storage cells or accumulators is a very useful addition to the equipment of a sub-station, especially when the load is of a very intermittent character. If no accumulators are provided it is obvious that each sub-station must be equipped with sufficient power to deal with the maximum possible load, although such a load may not be reached during any ordinary day. By using accumulators, combined with an automatic booster, it is possible to obtain a steady load on the power house, although the traffic load may vary enormously.

Owing to the fact that a suitable design for a railway motor demands a speed much higher than that at which the car axle should be driven in ordinary service, single reduction gearing is introduced between the motor shaft and the car axle, a pinion upon the former engaging a spur-wheel keyed to the latter.

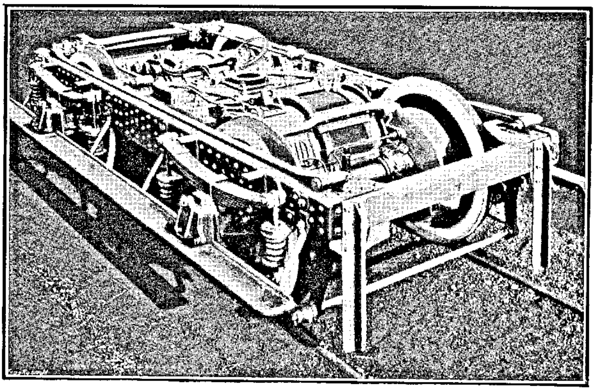
The usual gear ratio on motor car trains for suburban work having driving wheels of 36 to 42 inches diameter varies from about 2 to 3·7. In the case of electric locomotives it is possible to design motors of lower speeds so that the use of gearing can be entirely avoided, and the motor armatures are mounted directly upon the axles of the driving wheels; this is done in the case of the New York Central main line locomotives. On some lines, however, it is found necessary, in order to minimise the amount of non-spring borne weight, to introduce springs between the mass of the armature and the shaft, but to this subject we will refer again in the chapter on electric locomotives.



London, Brighton and South Coast Railway.
3-Car Single-Phase Train.

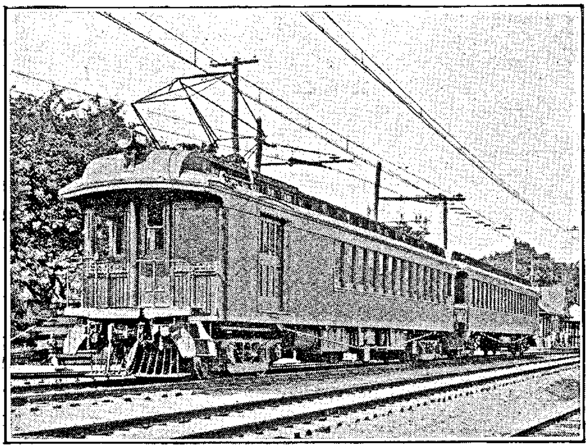
Single Phase Alternating Current System.—For this system energy is produced at the power house in the form of high-tension single-phase current. There have been attempts made to generate three-phase current and connect the various phases in such a way as to obtain single-phase current, but, from an electrical point of view, the results have been extremely poor.

The single-phase high-tension current is usually fed from the power house direct to the trolley line, but for long lines extra high-pressure single-phase current is transmitted to transformers suitably placed along the route and the pressure reduced as required to feed the trolley line. The ordinary trolley voltage is either 6,000 or 11,000 volts, but quite recently 15,000 volts has been used.



London, Brighton and South Coast Railway.
Single-Phase Motors, mounted on Truck.

To work the motors on the train a much lower voltage is required, as single-phase traction motors are not constructed for a higher voltage than about 800. The high pressure electrical energy from the current collector has therefore to be reduced to a suitable voltage for the motors by a transformer on the train. The motors are more or less of the same type and construction as direct current motors, except that the magnetic field is differently arranged so that the magnetic losses in the iron (due to the alternating current) may be reduced. The single-phase motor is not such a satisfactory machine as the D.C. motor. It weighs more for the same output, is less efficient and costs more to maintain—in fact, the motor may be looked upon as the weak point in the single-phase system. Its speed-torque characteristics are practically the same as those of the D.C. motor. The speed of the motor is regulated by varying the pressure supply to the motors, which is easily done by providing the transformers on the train with several "taps," thereby making different voltages obtainable. In the installation of high-tension apparatus elaborate precautions are necessary to ensure immunity from shock, but once properly installed the apparatus is quite safe in this respect. The apparatus takes up a great amount of space, but this is not so objectionable for a locomotive as it is for a multiple unit train. The motors are geared to the driving axles as D.C. motors are; but, owing to their speed being higher than that of the latter type, the gear ratio for driving wheels 42 in. in diameter is about 4.



New York, New Haven and Hartford Railway,
New Canaan Division. Single-Phase Train.

Three-Phase System.—For this system three-phase high-tension current is generated at the power house and dealt with in its distribution exactly as single-phase current. The overhead line consists of two conductors per track, each carefully insulated from the other. The usual pressure is about 3,000 volts between the conductors and earth. The term "three-phase current" is applied to alternating current transmitted through three conductors, the current in each conductor having the same frequency as, and a definite relation to, the currents in the other conductors. Alternating currents, as before explained, reverse many times per second, varying from a maximum in one direction to a maximum in the other. The time elapsing between the successive maxima in one direction is called the "period" of the current, and the number of periods per second is the "frequency." The frequency usually adopted for traction work is either 25 or 15. When currents having the same frequency attain their similar maxima at the same instant they are said to be "in phase" with each other. When this is not the case they are "out of phase," but they have a definite phase relation. The term "three-phase current" can therefore be defined as three alternating currents, having each a phase difference of 120 degrees, but having the same frequency. Currents not having the same frequency have no definite phase relation.

Three-phase motors differ radically from the D.C. and single-phase A.C. motors. They are commonly, known as "induction" motors, and consist of a fixed portion called the "stator" and of a moving part called the "rotor." The stator is supplied with three-phase current, while the rotor has no direct metallic connection with the source of supply, but has currents generated in its own coils by induction. The principle of action is that the three-phase current produces in the stator a magnetic field which rotates at a speed proportional to the frequency of the current, and induces currents in the coils of the rotor which produce a magnetic field in the rotor itself;

the interaction between the two magnetic fields causes the rotor to revolve.

The chief differences between direct current and single-phase alternating current motors (which for this comparison are practically identical) and three-phase motors are :—

(1.) In the D.C. and Single-Phase A.C. motors the speed for a given electrical pressure depends upon the load and, conversely, for a given load the speed depends upon the pressure. It will be remembered that this point has already been mentioned in the present chapter, a curve given in Fig. 4 showing how the speed varies with the load. The three-phase motor is, however, a constant speed motor, that is to say it runs at nearly the same speed whatever may be the load; while the speed is also independent of the voltage of the supply circuit, though depending upon the frequency of the current.

(2.) In the D.C. and single-phase motors the supply current must traverse the armature as it enters by the brushes and commutator. The supply voltage has on this account to be limited to avoid excessive sparking at the brushes. In the three-phase motor the supply current traverses the stator coils only, as there is no physical connection between the moving and stationary parts. The speed control of three-phase motors is rather difficult and does not lend itself so well for multiple unit control. During the last few years satisfactory motors have been made which can be arranged for two or more speeds, but this involves some complication in windings and connections.

Having outlined briefly the main features of each system of electric traction, we will now proceed to indicate their respective advantages and uses—a subject that has been very fully discussed during the last few years in various technical papers, although its highly technical nature will prevent our dealing with it *in extenso* here.

The D.C. is the oldest system, and is in use on nearly all the heavy electrified suburban lines throughout the world. It has been so satisfactory in its results—both operating and financial—that very conclusive proofs of the advantages of single-phase apparatus will be required before it supersedes the D.C. system. The use of 1,200 and 2,400 volts D.C. has increased the range of this system enormously. Its great advantage lies in the rolling stock equipment, due to the fact that a D.C. motor is much lighter, more efficient and more reliable than a single-phase motor for a given size, and the apparatus generally lends itself particularly well to multiple unit control. Its chief disadvantage lies in the distribution of power, which is effected by means of sub-stations requiring moving machinery. In practice it is found that for heavy and dense suburban services the D.C. system is the cheapest to instal and operate, although for much lighter services the single-phase system shows up better as regards capital cost.

The difficulty of using the D.C. system for comparatively long lines is the fact that it requires numerous sub-stations, which must be fairly close together in order to keep the voltage drop within the prescribed limits. However, experience has shown that even the D.C. 600 volt system can deal with lines 65 miles long, as shown by the West Jersey and Seashore Railway, which operates a heavy train service between Camden and Atlantic City, a distance of 65 miles. A considerable number of 1200 volts D.C. lines have been equipped in America, and are now in satisfactory operation, while in many cases it has superseded the single-phase system. For the electrification of the Melbourne suburban railways it has been decided to adopt the 1500 volts D.C. system after an exhaustive study of the various systems, and this system is now being adopted by the North Eastern Railway for the electrification of their line between Middlesbrough and Shildon. The Holcombe Brook branch of the Lancashire and Yorkshire Railway has been equipped by Messrs. Dick, Kerr and Co. with a 3500 volts D.C. system, while quite recently several railways in America have adopted the 2400 volts D.C. system. Where the service is dense and heavy 1200 or 1500 volts D.C. does not show many advantages over the 600 volts D.C. system, while the first cost is somewhat higher. Where the service is less dense, such as on several American inter-urban lines, the saving effected by 1200 volts D.C. is very marked, due to half the number of sub-stations being required and greater economy in copper. Another advantage of the 1200 volts D.C. system is the fact that cars or locomotives may be operated either at 600 or 1200 volts by connecting the motors all in parallel for 600 volt operation and two in series and two groups in parallel on a 1200 volt section. Without exception the results obtained with 1200 volts D.C. have been successful, and the apparatus once installed has caused no trouble whatever.

The single-phase system is still very young, and consequently very little is so far known about its capital and operating costs. The chief advantage of the system lies in the simplicity of the power distribution—it requires no sub-stations with moving machinery; but unfortunately experience has already shown that the limitations of the system are due to the rolling stock equipment. This is extremely heavy owing to the transformers and high-tension apparatus which are carried on the cars, while the motor itself is very heavy and less efficient than the D.C. motor. The excessive weight of the rolling stock makes the first cost extremely high, and the maintenance of the equipment is also very high, owing to the inherent disadvantages of the motor. The single-phase system lends itself better to locomotive than to multiple unit control, but its first cost, as already inferred, is generally higher than that of any other system. It is not well adapted for an extremely heavy and dense suburban traffic, but it is claimed that it is eminently suitable for main line work.

The Three-Phase system has up to now been chiefly used in Italy and Switzerland. It is not at all suitable for suburban work, and it is principally used for tunnel and main line work where stops are infrequent. The advantages of this system are (i) that the motor is very reliable and light (it is about the same weight as the D.C. motor), (ii) that the power transmission to the train is practically the same as that used in the single-phase system and therefore is fairly simple, and (iii) that the system lends itself better than any other to regenerative control, *i.e.*, it is possible to utilise the motors when descending a grade as generators, so that they can return current to the line. This feature is of value in mountainous districts. The chief disadvantage of the system is that it requires two overhead lines, each carefully insulated from the other, and this means practically a double system of overhead construction, leading to great complications at junctions and cross-overs. As already mentioned, the three-phase motor runs at approximately the same speed at all loads. If, therefore, a three-phase train has to ascend a gradient it does not travel at a reduced speed, as is the case with the two other systems, but maintains its full speed. This imposes severe "load peaks" on the electric supply station, whereas the reduced speed at which the D.C. and single-phase trains automatically run as soon as the gradient is reached protects the electric supply station from wide variations in its load. In regard to capital cost the three-phase system is generally the cheapest, where conditions are such that it can be installed. In the following table appear figures comparing some well-known types of motors :—

	DIRECT CURRENT.	SINGLE-PHASE.	THREE-PHASE.
Type of motor	Ge 69	WHB 280	Used on loco.
Manufacturer	British Thomson-Houston Co.	Siemens-Schuckert	Italian Westinghouse Co.
Hourly rating of motor in Horse Power ..	200	200	990
Full load efficiency of motor	92%	87%	93%
Weight of motor ..	5625 lb.	7080 lb.	27,000 lb.
Weight of motor per Horse -Power ..	28·1 lb.	35·4 lb.	27·3 lb.
Horse-Power per ton-weight of motor ..	79·5 H.P.	63·2 H.P.	82·1 H.P.

The above figures show that there is not much difference between the D.C. and three-phase motors in regard to weight and efficiency and that the single-phase motor is much heavier and less efficient.

Figures are also given, comparing a completely equipped D.C. motor car with a single-phase motor-car for approximately equal service.

In this last comparison no three-phase motor car is shown, as motors of this type are now only used on locomotives—to which reference will be made later on. The figures given show clearly the great weight of rolling stock when equipped with the single-phase apparatus, and this is an important item. Every bit of extra weight carried about means a greater power consumption, and the denser the service the more important does this item become.

	DIRECT CURRENT.	SINGLE-PHASE.
Railway on which motor car is used ..	District	London, Brighton.
Weight of complete motor car in tons	29·4	54
Number of motors per motor car ..	2	4
Rated horse-power of motor	200	115
Weight of all motors with gear cases .	5·60 tons	11·0 tons
Weight of remaining electrical equipment (controllers, contactors, etc.)	1·68 tons	7·0 tons
Total weight of electrical equipment	7·28 tons	18 tons
Weight of total electrical equipment in lb. per horse-power	40·7 lb.	87·8 lb.
Horse-power per ton-weight of electrical equipment..	55 H.P.	25·5 H.P.
Percentage which total electrical equipment constitutes of total weight of motor car..	24·8%	33·4%

At present it does not appear that the three-phase system is likely to be used on English railways. In 1902 this system was proposed for the Metropolitan Railway, but owing to the necessity of through running with the District Railway, which had already adopted the D.C. system, the matter was settled by arbitration. Both the D.C. and three-phase systems were minutely examined, and in the end the arbitrator decided that the D.C. system was the more suitable. This, so far, has been the only attempt to introduce the three-phase system into this country, and it would appear that for English conditions, as far as converting existing steam roads are concerned, the only two systems to be considered are the D.C. and the single-phase. As to which is the more suitable no general rule can be laid down; the local conditions in each case must be the deciding factor.

CHAPTER IV.

To transmit an electric current to a moving train it is necessary to have a continuous fixed conductor, which may either be a third rail or an overhead wire, and a movable conductor or collector fixed on the train. The fixed conductor follows the railway tracks, and the collector fixed upon the train moves along this and brings the current to the train.

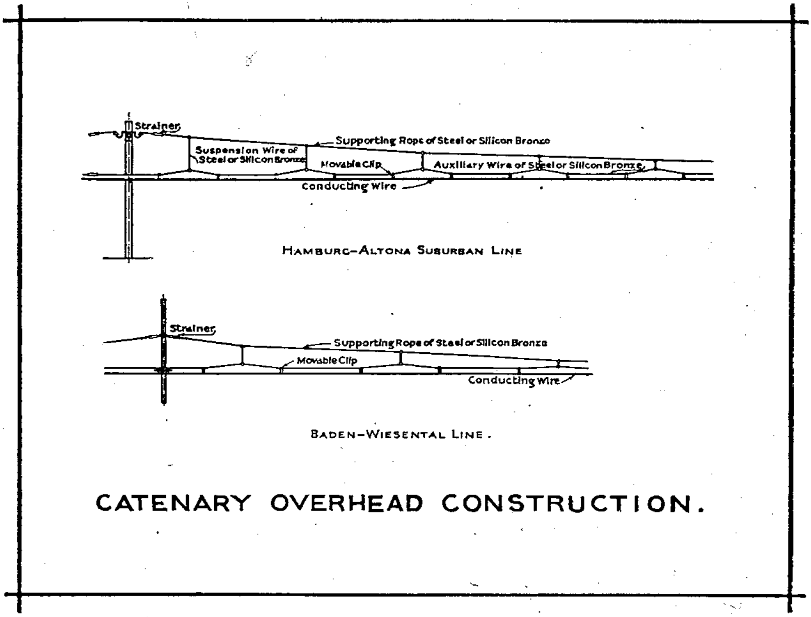

Strainer
Supporting Rope of Steel or Silicon Bronze
Suspension Wire of Steel or Silicon Bronze
Movable Clip
Auxiliary Wire of Steel or Silicon Bronze
Conducting Wire
HAMBURG-ALTONA SUBURBAN LINE
Strainer
Supporting Rope of Steel or Silicon Bronze
Movable Clip
Conducting Wire
BADEN-WIESENTAL LINE.
CATENARY OVERHEAD CONSTRUCTION.

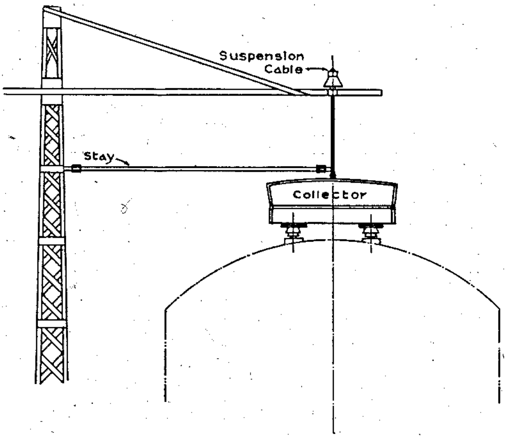
Fig. 6.

The third rail is used for direct current systems up to 1,200 volts, while for direct current tramways at 600 volts and electric railways from 1,200 to 15,000 volts, overhead conductors are used. The "overhead" system for railways is by many people associated with alternating current traction only, but there is no essential relation between the two, since direct current railways at 1,200 volts are using overhead equipment, and several will before long be in operation using 2,400 volts. On the other hand, alternating current cannot be commercially supplied to a train by means of a third rail, owing to the much greater resistance of a third rail for alternating than for direct current.

The current that can be collected from an overhead wire is much smaller than can be collected from a third rail, but it must be remembered that for the same power the current is reduced proportionally as the voltage is increased. At 650 volts we can, at starting, collect from a third rail with one collector shoe about 2,000 horse-power ; to collect the same power from an overhead conductor it is necessary to use a voltage of at least 4,000.

In the case of tramways the wire or conductor is attached to ears fixed to insulated brackets or span wires 100 to 120 feet apart. This method is quite unsuitable for railways, owing to the speed and voltage commonly employed, although with some modifications the ordinary trolley wheel or collector bow—similar to that generally used for tramways—could be used on country lines with an infrequent service and light trains at medium speeds.

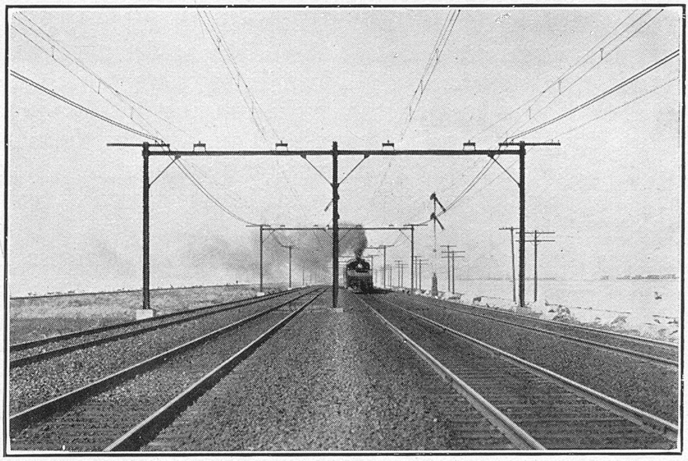
For higher voltages and speeds a method known as catenary construction is used. With this system the conductor or contact wire (as a rule this consists of a copper wire having a diameter of 0·4 in.) is suspended above the track by attaching it at regular intervals to one or two steel or silicon bronze cables, which have several times the strength of hard drawn copper cables. The suspension cable may be supported from bracket arms attached to side poles in the case of a single line, or may be supported from a gantry spanning the tracks where two or more tracks are in use. The suspension cable is heavily insulated at the point of support by means of porcelain insulators. Catenary construction relieves the contact wire from mechanical stresses, gives it a great flexibility and a high insulation.



SIDE POLE SINCLE CABLE SUSPENSION
Fig 7.

For spans up to 180 feet a single steel suspension cable, made up of nineteen strands of No. 12 S.W.G. (Standard Wire Gauge), and having an ultimate tensile strength of 96,500 lb. per sq. in., is generally used. For spans exceeding 180 feet a double cable suspension is sometimes adopted, in which case the conductor is attached to the two cables by rods—the two suspension cables may or may not be tied together. For single suspension cable the conductor may be suspended by hangers consisting of single galvanized steel wire.

On the London, Brighton and South Coast Railway the double catenary system is employed. The overhead work consists of lattice, girders or cantilevers mounted at the top of steel towers and carrying pairs of insulators on their upper or lower sides. From each pair of insulators a pair of catenary wires is carried to the corresponding insulators on the next girder or cantilever, and the contact wires are hung from these catenaries by means of short droppers, pitched about 10 feet apart. The catenaries are tied together, at the points where the droppers leave them, by means of horizontal ties. The catenaries are made from twelve stranded galvanized steel wires, each 0·088 in. diameter, while the contact wires are of copper 0·5 in. in diameter.



Tangent Four Track, 1,200 volt Catenary Line Construction on San Francisco Mole.

In this country the Board of Trade insists upon having a minimum clearance of 2 ft. 4 in. between the supports carrying the brackets or gantries and the railway carriage.

The current from the overhead conductor may be collected either by a trolley, bow or pantograph.

A trolley consists of a tapered tube, having at one end a fork holding a grooved gun-metal wheel, which runs underneath the conductor wire and is kept in contact with it by springs at a pressure of 25 to 35 lb.

This type is largely used for tramways and light railways. The bow collector is also used largely for tramway work, especially on the Continent. In this type of collector either a cylindrical roller or a contact shoe of aluminium or iron slides along the overhead wire, and the pressure between bow and wire is, as a rule, less than it is in the case of a trolley.

For railway main line working with high-pressure current a current collector should be so designed that in all circumstances it will remain in contact with the trolley wire as long as it is in the running position, and that it will be possible to raise it up against the wire or to lower it from the driver's cab without any risk. For this kind of work the bow collector is used in some modified form, and is generally raised or lowered by means of compressed air. The pantograph or scissors collector is used a good deal, as is shown in the various illustrations of single-phase trains. This type of collector does not require to be reversed when the direction of running is changed, but most of the other collectors, such as the trolley and plain bow, only operate in one direction.

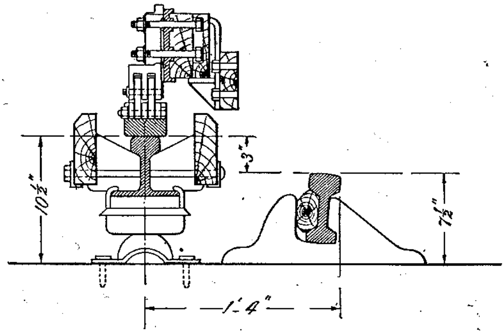
The height of the contact wire has a great deal to do with the operation of the collecting devices. European railways usually place the trolley wire 16 or 17 feet above the rails, while in America the usual distance is from 22 to 24 feet. It is evident that in all cases the overhead wire must be sectionized so that a single individual fault shall not cripple the whole system.

Third Rail Contact Lines.—When the third rail was first introduced ordinary common track rails were employed, supported by wooden blocks impregnated with paraffin. A great deal of attention has since been devoted to third rail construction, with the result that more suitable rail sections have been produced, which present a greater collecting surface to the contact shoe ; the chemical composition of the steel has been altered to increase the conductivity in order to obtain a steel of good wearing quality. With the exception of the upward and downward pressure of the collector shoe, as the case may be, a conductor rail has to bear practically no weight. The following table gives the chemical composition (other than iron) of an ordinary track rail, as specified by the Engineering Standards Committee, compared with the average chemical composition of a modern conductor rail :—

	Carbon, Per Cent.	Manganese, Per Cent.	Phosphorus, Per Cent.	Sulphur, Per Cent.	Silicon, Per Cent.
Track Rail ..	0·05 to 0·35	0·7 to 1·0	Not to exceed 0·075	Not to exceed 0·8	Not to exceed 0·10
Conductor Rail ..	0·05	0·2	0·05	0·05	Traces

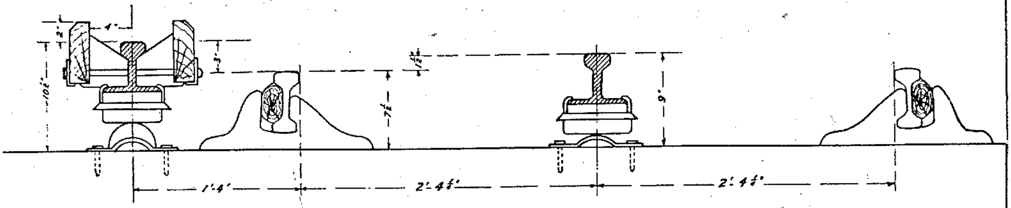
The current-carrying capacity of a conductor rail weighing 90 lbs. per yard approximates to that of a copper cable having a cross-section of 1 sq. in.

A very important question is the position of the third rail. According to the decision of a meeting held at the Railway Clearing House in March, 1903, the



Metropolitan and District Third Rail and Collector Shoe.

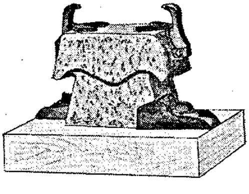
FIG. 8.



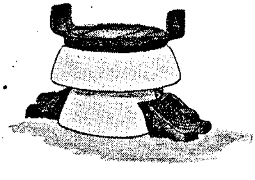
Metropolitan and District Third and Fourth Rail.

FIG. 9.

horizontal distance between the centre of the track and the centre of the third rail should be 3 ft. 11½ in., the third rail standing up 3 in. above the track rails. The District, Metropolitan and London Underground Tubes have, however, not altogether adhered to this recommendation, owing to tunnel clearances, but have adopted a standard of 3 ft. 8¼ in. for the horizontal distance. They have accepted the height above the track rails, as the rolling stock of any railway might at any time have to pass over a portion of an electrified line. The position of the fourth or return rail was also settled at the same meeting, it being decided to have this rail in the centre of the track raised 1½ in. above the track rails. It is necessary to place the fourth rail higher than the track rails to enable the collector shoe of a train to ride over any crossing without striking the track rails ; but at the same time it has to be kept low enough to prevent hanging coupling chains of goods wagons from fouling it.

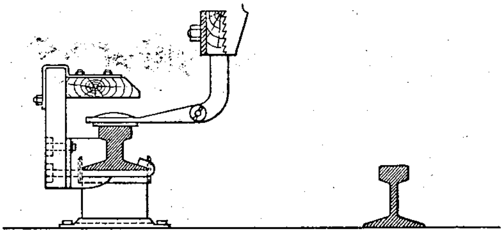


Reconstructed Granite Insulator.



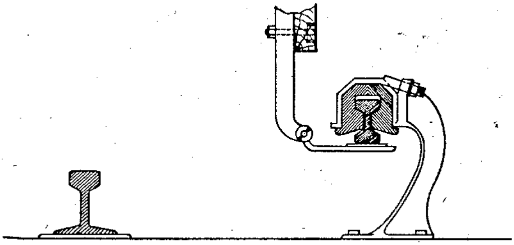
Type of Third Rail Insulator.

The conductor rails are mounted on insulators of either reconstructed granite or porcelain. The average distance between insulators is about 8·5 ft. Porcelain insulators are mostly used and are very reliable; the annual breakage due to blows, derailments, etc., only amounts to about 1 per cent. Between station platforms and at points where it is necessary for the railway staff to cross the tracks the conductor rail is protected from accidental contact by boards erected vertically on either side of the live rail. This method is used on the Lancashire and Yorkshire, District and Metropolitan Railways. Another form of protection, as shown in the illustrations, is used on the Long



LONG ISLAND RAIL ROAD
TOP CONTACT THIRD RAIL

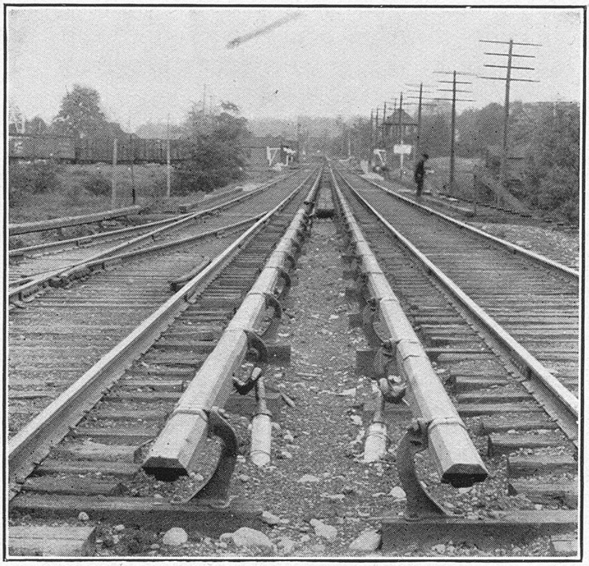
FIG. 10.



NEW YORK CENTRAL RAILROAD
UNDER CONTACT THIRD RAIL

FIG. 11.

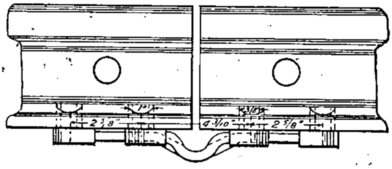
Island and several other American railways. It is a very effective protection, but requires the use of a somewhat different collector shoe.



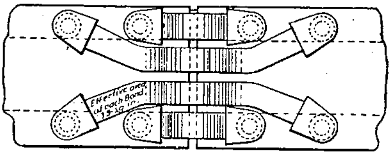
View of Protected Type of Third Rail.

The New York Central has adopted a third rail (see the above illustration) which is of the under-contact type. This rail is entirely protected by a wooden cover which fits over the rail. The type has several advantages, the most important being that it is practically safe in all circumstances. Unfortunately it is not possible to adopt this rail for our railways, as it requires greater space than our clearances allow. A third rail similar to that in use on the New York Central is used by the Central Californian Traction Company at a pressure of 1,200 volts—the highest pressure so far employed on third rail installations.

It is necessary that the third rail should in all cases be divided into sections, so that any fault that may occur can be isolated at once. We have seen that conductor rails are made of high conductivity steel. In order to maintain a high conductivity throughout the various lengths of conductor rail it is essential to keep the electrical resistance at the joints as low as possible. The rails are connected not only mechanically but also electrically, and this work is known as "bonding." A bond generally consists of a few flexible copper cables or strips which form the electrical connecting link between the rails. The type of bonding on the London Underground Railways consists of four copper bonds per joint, having a sectional area of 1·33 sq. in. The copper conductors are furnished with two large terminals which pass through holes in the web of the rail. The holes are rimered out clean just before the bond is put in. The terminals are then expanded with considerable force



Short Bond is 5" Long Bond 10¾" between Terminal Centres



PROTECTED TYPE OF BOND
ON LONDON UNDERGROUND ELECTRIC RAILWAYS

FIG. 12.

(hydraulic pressure is generally used) so as to drive the metal of the bond into intimate contact with the rail. It is, of course, necessary to anchor conductor rails to prevent creeping, whilst allowing ample margin for expansion. On some railways the conductor rails are anchored every 130 feet to a special insulator, whilst on other lines they are anchored every 300 feet.

Collector shoes—which are made either of cast iron or steel—are pressed against the conductor rail, either by their own weight or springs. They should be so designed as to be able to rise and fall freely, and thus adjust themselves to the irregularities of the surface of the conductor rail. The weight of the collector shoes and pressure against the conductor rail vary enormously. The weight of a new shoe in the case of the District Railway amounts to 23 lbs., while on the Lancashire and Yorkshire Railway it amounts to 90 lbs. The illustrations and diagrams show types of collector shoe adapted to suit the various forms of third rail construction.

Return Circuit.—The question of using an insulated fourth rail instead of track rails is one that requires careful consideration. As before mentioned, it has not been found necessary, either on the Continent or in America, to use an insulated fourth rail. When tramways were first employed, the Board of Trade laid down regulations that the maximum pressure drop along the rails should not exceed 7 volts. This was done to avoid troubles due to electrolysis, which had caused, in some cases, considerable damage to water and gas pipes. With the comparatively small current used for tramway work no great difficulty was experienced, but with heavy trains as used on electric railways, it is a much more difficult matter. The chief objection to the fourth rail is the additional space it occupies and, of course, the extra cost; but the chief difficulty to overcome is at points and crossings, where both insulated rails have to be discontinued. Where the track rails are used as the return circuit, it is necessary to bond the rails as the conductor rail, while cross-bonds inter-connecting the track rails are placed at suitable distances apart. It has been urged that when track rails are used for the return circuit it will be impossible to use track circuiting and automatic signalling, but there is no longer any doubt in this respect, since alternating current, which does not interfere with the direct current used for traction and passes through the rails at the same time, can be used for these purposes. Such systems are in use with great success on nearly all the heavy electric railways in America, and have recently been introduced into this country on the Central London Railway. The Lancashire and Yorkshire Railway use a fourth rail (not insulated) connected to the track rails. It merely adds to the conductivity of the track rails, and tends to keep the voltage drop low. It has, however, not been used for their extensions. The voltage drop in track rails, when using either single or three-phase alternating currents for traction, is even greater than with direct current, owing to the much greater resistance a rail offers to alternating than to direct current. On the Brighton Railway special boosting transformers are employed to keep the voltage drop down. It is true that the electrolytic effect of alternating currents is far less than that of direct current, but on the other hand the disturbance caused by alternating currents to telephone and telegraph instruments is considerable.

We will now briefly consider the advantages and disadvantages of overhead construction and third rail.

Among the advantages of a third rail may be mentioned its low capital and maintenance costs. It is a thoroughly mechanical job, and experience has shown that it gives no trouble whatever. Mr. Aspinall, in his presidential address to the Institution of Mechanical Engineers, says :—

> "The third rail is easy to lay, cheap to maintain, and has proved by long experience to be the cause of few accidents."

The third rail can be maintained (and this is done in practice) without the current being cut off, and insulators can be replaced or other adjustments made during ordinary traffic.

There are only two serious objections which can be urged against the third rail—namely, the risk of shock, and the fact that it is extremely unlikely that a higher pressure than 1500 volts can be used. The risk of shock has proved to be a very small one; but with overhead equipment there is no risk at all, and this is the only advantage of overhead equipment apart from the fact that very high voltages can be used. Experience has proved that the first cost of overhead equipment is much higher than a third rail installation. Among other disadvantages of the overhead wire is the difficulty to sight signals. The cost of maintenance, also, is much greater than for third rail equipment, as no work can be carried out without full possession of the road with the current cut off the line, as it is necessary to use a special car with a platform to get at the wires. In England it is a difficult matter to install overhead equipment, our tunnel clearances being much smaller than those in America and on the Continent; there is a similar difficulty with low bridges.

CHAPTER V.

THE various systems of electric traction having been considered, let us now turn our attention to the important subject of electric locomotives. In the next chapter we shall show that for suburban traffic it is absolutely necessary to employ motor-car trains so as to get in and out of terminal stations without shunting operations and loss of time. Furthermore, a suburban service requires very high acceleration, and this can only be obtained by utilising a large proportion of the total train weight for the purposes of adhesion. In cases where the above conditions are not so imperative, electric locomotives would in all probability prove more suitable than motor-car trains.

So far electric locomotives have been chiefly used for handling goods and main line passenger trains on the electrified sections of suburban lines, such as the New York Central line, but they are also used for short sections of purely main line work, such as the well-known Simplon Tunnel and the Dessau-Bitterfeld section of the Prussian State Railways. For obvious reasons this class of traffic must be worked in the same way as it is now worked by steam, and for these services some very powerful electric locomotives have been built.

As already indicated, an electric locomotive possesses some very substantial advantages over motor-car trains. Among these may be mentioned the following :—(*a*) A considerable reduction in the cost of electrical equipment, owing to the concentration of the electric installation and the fact that practically no change to existing rolling stock is required, (*b*) The maintenance of the electrical equipment is lower than on motor-car trains, due to a less number of motors being employed, and also because the motor equipment is more accessible and can receive better supervision, while the number of parts is smaller with the larger motors.

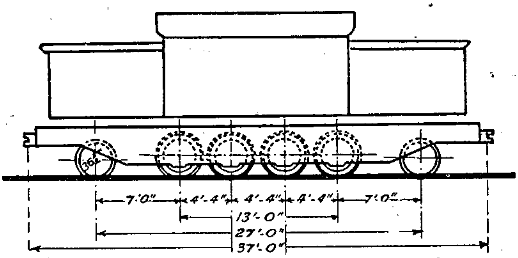
When first electric locomotives were constructed, attention was chiefly directed to the perfection of the electrical apparatus, and appreciation of the importance of mechanical features was neglected, it being assumed that the characteristics of an electric motor, *viz.*, uniform torque and rotary motion, made its application to locomotives a simple matter; but experience has taught that there are other desiderata, such as high centre of gravity, proper weight and wheel base distribution. At first sight it appears easy to transmit power from motor to shaft, but in practice this is found not to be the case. Electric locomotives can be classified as follows, according to the method of power transmission from motor to axle:—

I. Gearless motors with armature mounted either directly on the axle (as in the original Central London and New York central main line locomotives), or on a quill surrounding the axle and driving the wheels through flexible connections as in the New York, New Haven and Hartford passenger locomotives.

II. Geared motors mounted between or above axles with gear connection to the axle, (*a*) with bearings directly on the axle and nose supported on spring borne parts of the locomotive (as in multiple unit motor-cars, and Metropolitan and District locomotives); (*b*) with bearings on a quill surrounding the axle and nose supported on spring-borne parts of the locomotive or motor rigidly bolted to spring borne parts of the machine, the quill having sufficient clearance for axle movements, as in the New York, New Haven and Hartford freight locomotives; (*c*) motors mounted rigidly on spring-borne parts and power transmitted through gears to countershaft, thence to the drivers through Scotch yokes and side rods.

III. Motors which drive on to a separate shaft connected to driving wheels by means of connecting-rods and cranks. These are now largely in use on the Continent.

Omitting from consideration the gearless motors of about fifteen years ago, which were supported directly on the axle, the first attempt to solve the problem of high speed and large capacity was made in the case of the direct current locomotives built for the New York Central Railroad, and these locomotives have proved very reliable and highly efficient in operation, while the simplicity of design makes them particularly adapted for direct current freight and passenger services. They are used for hauling main line trains over the electrified suburban section from New York to North White Plains on the Harlem Division—a distance of 24 miles—and from New York to Croton on the Hudson Division, a distance of 34 miles. All trains for points further than Croton or North White Plains leave New York attached to electric locomotives, which, on arrival at the latter places, are detached, steam locomotives being substituted to continue the journey. All suburban trains working within these limits are motor-car trains.



N.Y. Central & Hudson River Railroad.
Passenger D.C. Locomotive. Original Type.

FIG. 13.

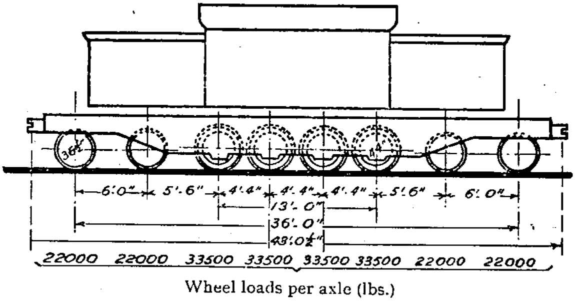
The locomotive has four driving axles, on each of which is mounted the armature of a gearless electric motor having a normal rating of 550 H.P. The total rated capacity of the locomotive is 2,200 H.P., although for limited periods a considerably greater power may be developed, thus giving the locomotive greater capacity than the largest steam locomotive yet in existence. The motors mark a noteworthy departure in construction, gears and axle bearings being dispensed with; and they represent practically the acme of simplicity. The armatures are built directly upon the axles, giving the advantage of direct application of power to the driving axles, and thus avoiding the losses in power of gear and pinion usually encountered with geared motors. The motors are of the bi-polar type, *i.e.*, there are only two pole pieces, which are practically part of the truck frame and have flat vertical faces; therefore the armature can have a large free vertical movement without danger of striking the pole pieces. The maximum weight of the motor, consisting of its field and frame, is carried with the truck frame upon the journal box springs outside the driving wheels. This construction, it is claimed, besides being strong and simple in design, greatly facilitates repairs and renewals, as an armature with its wheels and axle may be removed by lowering the complete element without disturbing the fields or any other part of the locomotive, and a new element may be inserted in its place. All parts are also thoroughly accessible for inspection and cleaning. Power is supplied to the locomotive by means of an under-type running third rail at a pressure of 650 volts. The following are particulars of this locomotive :—

Total rated horse-power (hourly rating) ..	2,200
Number of motors	4.
Transmission of motor power to axles ..	Gearless.
Voltage and systems	600 volts. D.C.
Diameter of driving wheels	44 ins.
Diameter of guiding wheels	36½ ins.
Total wheel base	36 ft.
Rigid wheel base	13 ft.

Length overall	43 ft. ½ in.
Width overall	10 ft. 1 in.
Weight of electrical equipment	26·8 tons.
Weight of mechanical equipment	75·7 tons.
Total weight	102·5 tons.
Dead weight per driving axle	5·76 tons.
Total weight per driving axle	15·85 tons.
Total weight per guiding axle	9·83 tons.
Horse power per ton weight of locomotive..	21·5.

One locomotive is capable of handling a 450-ton train at a speed of 65 miles an hour on a level track. From the above table it will be seen that the dead weight per driving axle is 5·76 tons, which is about the same as in a modern steam locomotive.

Forty-seven locomotives of this type are now in use, and have given great satisfaction. The original locomotives had the wheel arrangement 2-8-2, but owing to "nosing"‡ and hard riding qualities the two-wheel guiding trucks were altered to four-wheel trucks, so that the present locomotives have the wheel arrangement 4-8-4. It has been asserted that the "hard riding qualities" of the original locomotives was due to the low centre of gravity, but Mr. Sprague



N.Y. Central & Hudson River Railroad. Passenger D.C. Locomotive. Revised Type.

FIG. 14.

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‡ "Nosing" may be defined as a more or less destructive action in which the rails are alternatively subjected to flange pressures tending to spread the gauge.

has stated before the American Institute of Electrical Engineers that this was not the case—rather was it due to the absence of sufficient resistance in the two-wheel truck centring springs to prevent nosing. The use of four-wheel guiding trucks and lateral motion springs on the driving axle boxes effected a marked improvement in the riding qualities.

It is interesting to compare the weights of electric trains with those of steam trains used on the through service of the New York Central.:—

ELECTRIC.	
Electric Locomotive	102·5 tons.
8 Pullman Cars	356 tons.
Total	458·5 tons.
STEAM.	
Pacific type locomotive ..	154 tons.
8 Pullman Cars	356 tons.
Total	510 tons.

This shows a saving in favour of electric traction of 51·5 tons or 10%

The City and South London Railway (the oldest tube line in the world) originally adopted gearless electric locomotives, and these are still being used with considerable success. The weight of the City and South London locomotive varies from 12 to 16 tons, and the whole weight of the motor is non-spring borne. The Central London Railway also at first adopted locomotives fitted with gearless motors. The armatures of these motors were directly wound on the axles, and the non-spring borne weight per axle amounted to 8¼ tons, which is nearly 3 tons more than on the New York Central locomotives. Much difficulty was experienced with the Central London motors on account of the large non-spring borne weight and the vibration troubles caused by a rather weak permanent way construction. There are several geared locomotives in use belonging to Class IIa. which have given great satisfaction, among their number being the locomotives on the District and Metropolitan railways. Geared locomotives are highly satisfactory where low and medium speeds are required and where a reduction from the armature speed is necessary. The British Thomson Houston Company supplied several locomotives to the Metropolitan Railway, and these are used for hauling the Great Western and Aylesbury " through " trains over the electrified sections. They are of the double-truck type, with box-shaped cab; weigh, when fully equipped, 47 tons; and on a 600 volt circuit are capable of drawing a 120-ton passenger train on the level at a speed of 35 miles an hour, and of starting with the same load on a grade of 1 in 44. They are provided with four motors of 200 H.P. each, giving a total capacity of 800 H.P., while the gear ratio is $\frac{64}{19}$=3·36. Further particulars are as follow :—

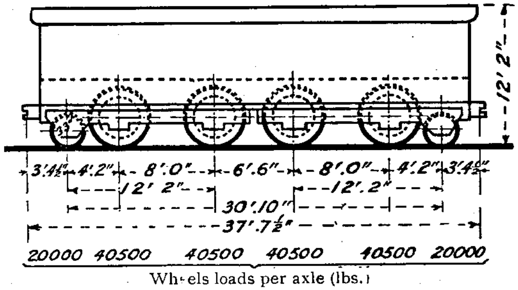
Length over buffers	36 ft. 6 ins.
Length over cab, headstocks..	30 ft.
Truck base	17 ft.
Wheel base of each truck ..	7 ft. 6 ins.
Width overall	8 ft. 7 ins.
Diameter of wheels	3 ft. 2 ins.

Some very powerful 600-volt direct current geared locomotives have been built by the General Electric Company for the Detroit River Tunnel, which connects the tracks of the Michigan Central Railroad in the United States to those in Canada. They are used for moderate speed passenger traffic and heavy freight service, and haul the steam trains over a distance of about 4·5 miles. These locomotives are of an articulated 0-4-4-0 type, weighing 89·5 tons, and giving a weight of 22·3 tons per driver. The motor equipment consists of four 300 H.P. motors, with a total capacity of 1,200 H.P. and an overload capacity of 1,600 H.P. The gearing between the motor and driving axle has a 4·37 reduction, and the driving wheels are 48 ins. in diameter. The gears are shrunk to an extension of the driving wheel hub, and there are two gears and two pinions per motor, one at each end of the armature shaft. This form of construction is adopted on account of the unusually heavy torque and the excessive overloads to which the motors are liable to be subjected in a heavy railway service. The motors are designed for forced ventilation; while the control is of the multiple unit type, so that two or more locomotives can be operated in multiple unit when necessary. The articulated running gear may, broadly speaking, be considered as consisting of two four-wheeled trucks coupled together by a massive hinge which is so designed that the rear truck is able to resist any tilting tendency of the forward truck. The two trucks are thus combined in a single articulated running gear having lateral flexibility with vertical rigidity. Each locomotive is capable of hauling a goods train weighing 800 tons (exclusive of its own weight), on the ascending maximum 1 in 50 gradient, at a speed of not less than 10 miles an hour, and of hauling a passenger train weighing 310 tons (exclusive of weight of locomotive) on the same gradient at not less than 20 miles per hour.

Detroit River Tunnel.
Two Electric Locomotives hauling a 1,400 ton freight train.

The New York, New Haven and Hartford Railway has built several single-phase locomotives in which different methods of transmission are employed.

The first type of locomotive, of which about forty are in use, has the wheel arrangement 2-4-4-2. A gearless motor for each driving axle is mounted on a quill flexibly connected to the driving wheels, thereby reducing the weight on the axles to a minimum. The particulars of these locomotives are as follows :—



NEW YORK NEW HAVEN & HARTFORD RLY.
SINGLE-PHASE PASSENGER LOCO.

Fig. 15.

Total rated horse-power (hourly rating)	960.
Number of motors per locomotive ..	4.
Voltage and System	11000 volts single phase.
Weight of electrical equipment	21 tons.
Weight of mechanical equipment ..	40·5 tons.
Total weight	91·5 tons.
Horse power per ton weight of locomotive	10·5.
Wheel arrangement	2–4–4–2.

This locomotive is capable of handling a train weighing 250 tons at a speed of 60 to 65 miles an hour on a level track.

Another class of locomotive used for high speed freight and medium speed passenger service belongs to Class II. (*b*). A pinion at each end of the motor connects with a flexible gear, the centre of which is rigidly secured to a quill surrounding the axle. The flexible gear overcomes the difficulty in securing tooth alignment and division of load, which are likely to occur when rigid twin gears are used. It is the only electric locomotive equipped with spur-geared motors bolted rigidly to spring supported parts of the locomotive; each driving wheel is driven through helical springs, the arrangement being such that the driving wheel has practically free vertical play. The locomotive has two trucks, the draw-bar pull being transmitted through the truck frames. It is an exceptionally easy-riding machine, and a speed of 40 miles an hour was attained on a level track with a 1,600 ton train.

Particulars of this locomotive are:—

Total rated horse-power (hourly rating) ..	1,260.
Number of motors per locomotive ..	4.
Voltage and System	11000 volts Single phase
Weight of electrical equipment ..	58 tons.
Weight of mechanical equipment ..	58 tons.
Total weight	116 tons.
Total weight per driving axle	20·3 tons.
Horse-power per ton weight of loco. ..	10·9.
Wheel arrangement	2–4–4–2.

The wish to secure the good riding qualities of the high-speed steam locomotive, and at the same time avoid the difficulties and limitations imposed by mounting the motor concentric with the axle, has led to the adoption of side rods for transmitting the power from the motor to the wheels. The motor is mounted inside the cab instead of under it, so that all parts are readily accessible and quite protected from dust and dirt; and the position of the motor inside the cab raises the centre of gravity of the locomotive to a height corresponding to that of a steam locomotive. The position of the centre of gravity is a very important point. Mr. Aspinall in his address to the Institution of Mechanical Engineers gave the following figures:—

HEIGHT OF CENTRE OF GRAVITY ABOVE RAIL LEVEL.

10-wheeled bogie passenger engine ..	66 ins.
8-wheeled radial tank engine	58 ins.
Liverpool & Southport motor car ..	45 ins.
Liverpool & Southport motor bogie ..	22 ins.

Mr. Aspinall was one of the first to draw attention to the fact that, in his opinion, the serious side-wear of rails which has taken place on the curves of electrified railways is due to the low centre of gravity of motor trucks.

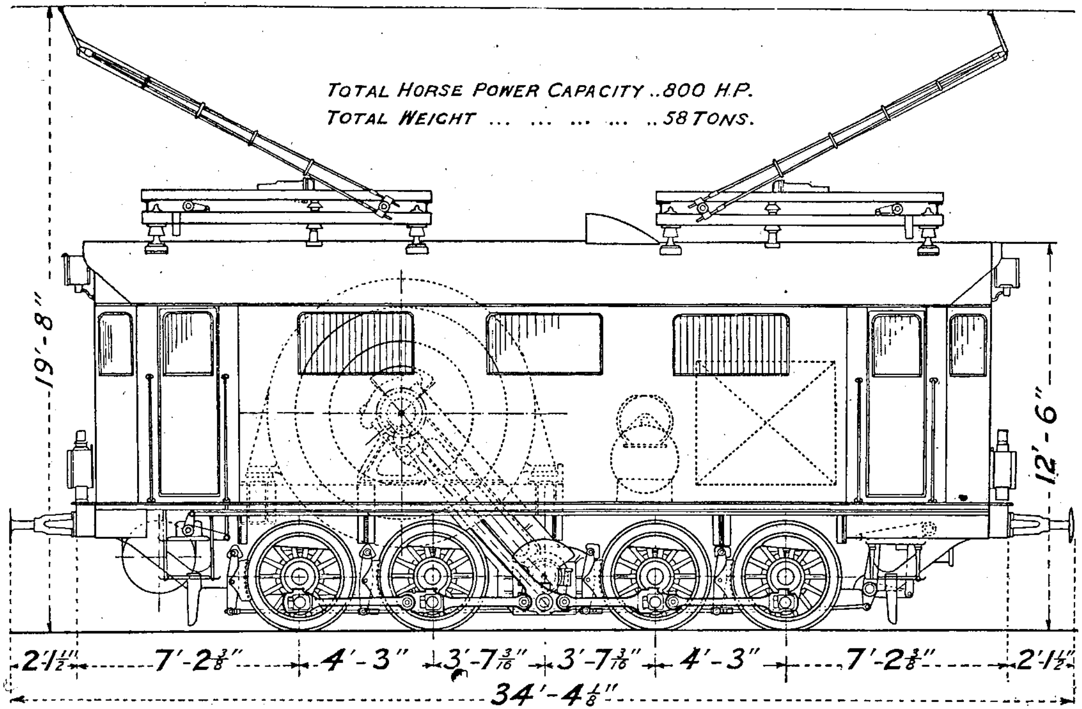
It is assumed that the lower the centre of gravity the harder will be the stresses and the hammer blows applied in a horizontal plane to the inside edges of the rail head, resulting from oscillation due to even the slightest unevenness of the track. The higher the mass of the locomotive is placed above the axles the greater will be its restraining influence against lateral motion on the part of the wheels. Of course it is not at all certain that these theories are correct, as we find that the centre of gravity in the original New York Central locomotives was only 44 ins. above the rail, and since the 2-wheeled guiding trucks have been altered to four-wheeled trucks the centre of gravity has been lowered to 40 ins. with excellent results. Probably if the centre of gravity were raised to its original height an even better result would be obtained. Theoretically an electric locomotive, having no unbalanced moving parts and exerting a fairly uniform tractive effort throughout each revolution of the wheels, ought to be easier on the track than a steam locomotive, whose wheels are actually lifted off the track when running at a high speed owing to unbalanced forces. At one time it was accepted that "nosing" of a steam locomotive was largely due to imperfect balancing, but, since it has been found that the same action develops in electric locomotives, this theory no longer holds good. With the early steam locomotives it was considered important to keep the centre of gravity low, but within the last few years it has been realized that a high centre of gravity contributes to steadiness in running and diminishes the lateral pressure upon the outer rail in curves. Raising the centre of gravity beyond certain limits, however, increases the tendency of a locomotive to overturn. Experience has shown that electric locomotives with a low centre of gravity will not increase the track maintenance provided that the armature and motor frame are not too rigidly mounted, that either two or four-wheeled guiding trucks are employed, and that the weight and power are well distributed.

Mr. George Gibbs, who has tested many types of electric locomotives for the Pennsylvania Railway and who has had a great deal of experience with this difficult subject, stated in his Paper on Electric Traction in America before the International Railway Congress in Berne, 1910 :—

> " It was found that all types of locomotives were practically steady at speeds under 40 miles an hour, but above this speed marked differences appeared ; that the steadiest riding machines were those with a high centre of gravity and with a long and unsymmetrical wheel base. In other words, the nearer steam locomotive design is approached in wheel arrangement, distribution of weight, height of centre of gravity and ratio of spring borne to under-spring weight, the less the side pressures registered on the rail head. In addition to the excessive side pressures on the rail head, due to the oscillation and " nosing " of a low centre of gravity machine, abnormal track effects may be caused by the vertical pounding due to a large non-spring-borne motor weight or to weights with imperfect spring cushion. A remedy for all these defects appears to mean a combination of driving and carrying wheels, an unsymmetrically disposed wheel base and the setting of the motors on the main frames above the axles."

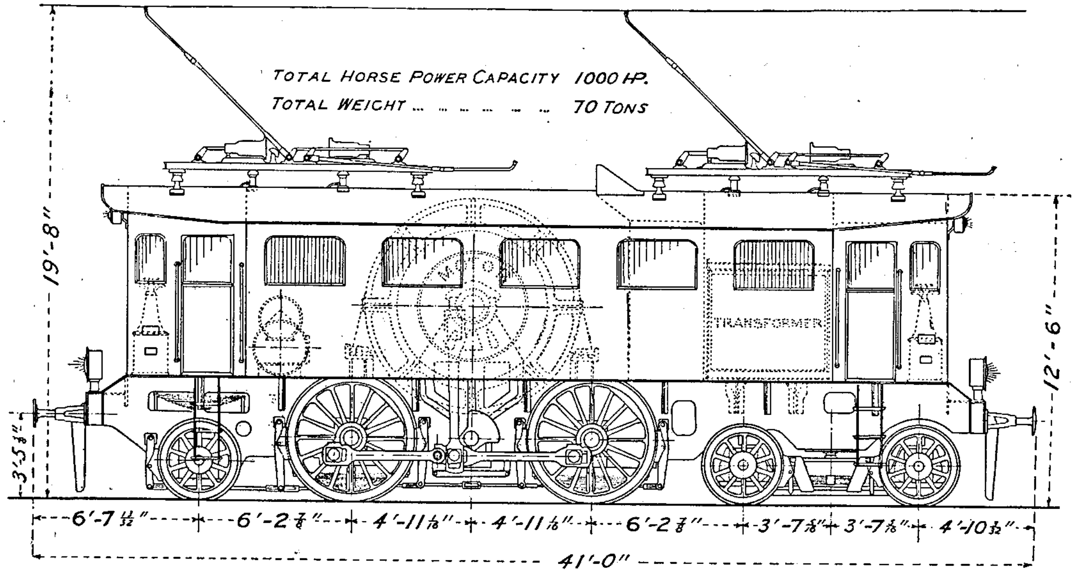
This leads us to consider locomotives in which the power from motor to axle is transmitted through connecting rods and cranks—a design much favoured by Continental engineers and quite recently to some extent by engineers in America. In 1904 Messrs. Ganz of Buda-Pesth, when building more three-phase locomotives for the Valtelina line, adopted connecting rods and cranks to transmit power from the motor to the axle. The first Valtelina locomotives supplied in 1902 by Messrs. Ganz were of the gearless type with the armatures on the driven axles. "The 1904" type is fitted with two three-phase motors of 450 H.P.

each, and has two normal speeds, the first being 37 to 43 miles an hour and the second from 18·5 to 21·5 miles per hour. The motors are mounted between the driven axles, and act on a connecting rod by means of cranks. The locomotive, which is supplied with three-phase current at 3,000 volts, has a total weight of 62 tons, 42 of which come on the driving wheels. The total length of the locomotive is 38 ft., and the wheel base between each driving wheel is 7·7 ft. The diameter of the driving wheels is 59 ins. The locomotive has the wheel arrangement 2-6-2 and is capable of dealing with 250 ton passenger trains and 400-ton freight trains. This was the first large type of locomotive to employ connecting rods for the transmission from motor to axle. In nearly all coupling-rod transmission locomotives the work is done by one or two large motors. As a single axle cannot utilise the power of such large motors, and as the axle load is limited, several axles must be coupled up. On lines where there are many gradients it is a great advantage to have as many driving axles as possible, for with heavy train loads now the rule, time in the case of an express service can only be saved by increasing the speed on ascending gradients, and this requires a great tractive effort. The connecting-rod system makes it possible to dispense with the complete enclosure of motors, thus ensuring more favourable cooling conditions. On the other hand it may appear retrogressive to advocate the use of cranks, connecting rods, etc., which, of course sacrifice the advantages of rotary motion. Among the well-known types of locomotives belonging to this class may be mentioned the single-phase locomotives constructed for the German State Railways and in use on the Dessau-Bitterfeld main line. They are designed for a line voltage of 10,000 volts at a frequency of 15 cycles. The express locomotives have the wheel arrangements 4-4-2 (like the Atlantic type



Single-Phase Freight Locomotive (Prussian State Railways).

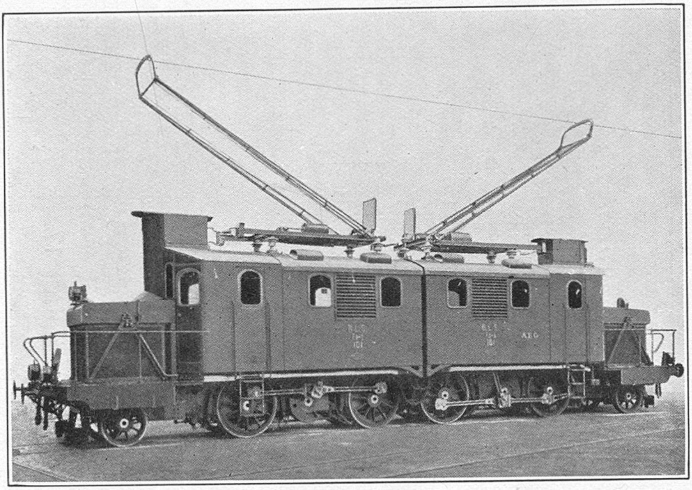
FIG. 16.



Single-Phase Express Locomotive (Prussian State Railways).

FIG. 17.

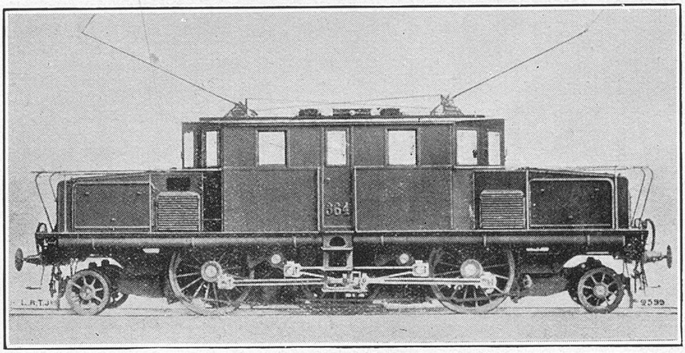
of steam locomotive) and are fitted with one motor only, which has an approximate hourly rating of 1,000 H.P. The motor is mounted in the centre of the locomotive, and works with vertical driving rods on to the intermediate crank shaft. The motor and intermediate crankshaft bearings are connected by means of a strong steel casting in order to ensure perfect rigidity. The diameter of the driving wheels is 63 ins. and that of the bogie and trailing wheels 39⅜ ins. The total weight of the locomotive is about 70 tons, and the adhesive weight about 33 tons, while the horse-power output per ton weight of locomotive is 14·3. This type of locomotive is able to haul a 400 ton train at an average speed of 44 miles an hour. The freight locomotives have four coupled axles and weigh about 58 tons, so that the weight per driving axle is 14·5 tons. The locomotives



Single-Phase Locomotive for the Bernese Alps Railway Co.
Total weight, 93 tons; Voltage, 15,000; Total horse-power capacity, 1,600; Adhesive weight, 68 tons.

are fitted with one motor only, having an hourly rating of 800 H.P. In these locomotives the intermediate crankshaft is placed exactly in the centre. Contrary to the arrangement in the express locomotives, however, the motor is not placed vertically over the intermediate crankshaft, but is mounted some distance away in order to obtain a better weight distribution. The motor works, therefore, with the driving rod at an angle to the intermediate crankshaft. This system of driving possesses the advantage that the strains on the intermediate crankshaft are not so great as where the driving rods are vertical. The locomotives can haul a 700-ton train (including their own weight) continuously at a speed of 19·8 miles an hour, and a 1400-ton train for one hour at a speed of 15·5 miles an hour. Several well-known Continental makers have supplied single-phase locomotives to the Prussian State Railways, but space prevents dealing with all their details. Lately, however, there appears to be a tendency in the case of freight locomotives for the Prussian State Railways to install two to four motors, which drive the axle through gearing, these being very much of the same type as the freight locomotives constructed for the New York-New Haven Railway already described. Some very powerful single-phase locomotives have been made for the Midi Railway in France, but they are more or less of the same type as those above described. It appears that all these locomotives have given satisfaction, but little has been published regarding maintenance and operating costs.

The three-phase locomotives used on the Simplon line, which is probably the most important international main line operated electrically in Europe, employ also a coupling-rod transmission. The line between the Swiss and Italian termini is about 13·7 miles long, with a maximum gradient of 1 in 143. All trains, both goods and passenger, are exclusively hauled by 3-phase locomotives fed from an overhead trolley at a pressure of 3,000 volts. The older type of locomotive supplied in 1907 had the wheel arrangement 2-6-2, but those built in 1909 are of the 8-wheel type, the weight of the engine being equally distributed on the four axles. With a view to facilitate the taking of curves, the wheel-base, however, is not rigid, the front and back coupled wheels being mounted on radial trucks, which permit a slight radial and lateral play. The two central axles are fixed and are 15 ft. 1⅛ in. apart, while in order to facilitate the taking of curves in the absence of trailing wheels, the wheel diameter has been reduced from 64·5 ins. in the old type to 44¼ ins. in the new. In the older type the motors are fixed rigidly inside the frame and transmit the torque to the driving wheels by cranks and coupling bars. The same plan has been adopted in the new locomotives, but on account of the very long wheel-base certain modifications have been made. The locomotives are capable of hauling a 300-ton passenger train at 43·5 miles an hour and a 400-ton goods train at 21·7 miles an hour, but in practice these loads have been exceeded, the passenger trains

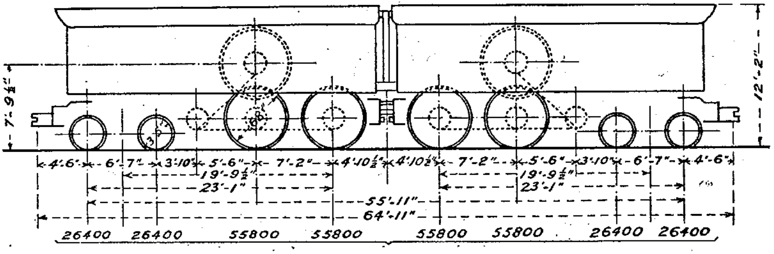


Simplon Tunnel Locomotive, 1907 type.

weighing frequently 350 tons and the goods trains 650 tons, each of which is hauled by a single locomotive. The chief electrical improvement in the new type is that of obtaining economically four running speeds instead of two. The following are particulars relating to both types of locomotives :—

SIMPLON 3-PHASE LOCOMOTIVES.

	Type. 1907.	Type. 1909.
System	3-Phase.	3-Phase.
Voltage	3000.	3000.
Number of motors	2.	2.
Total H.P. Capacity	1100.	1700.
Total weight in tons	62.	68.
Adhesive weight	44.	68.
Weight of electrical equipment in tons	29.	35.
Weight of mechanical equipment in tons	33.	33.
Wheel arrangement	2–6–2.	0–8–0.
Weight per driving axle in tons ..	14·6 .	17.
Length over buffers	40 ft. 5 ins.	38 ft. 2 ins.
Total wheel base	31 ft. 10 ins.	26 ft. 3 ins.
Diameter of driving wheels	64½ ins.	44¼ ins.
H.P. output per ton weight of loco.	17·8.	21·8.



Wheels load per axle (lbs.)

PENNSYLVANIA RAILROAD D.C. ARTICULATED LOCOMOTIVE
New York Terminal Passenger Service.

Fig. 18.

The Simplon line is of special interest on account of the long period of time it has been in operation. At first great trouble was experienced with insulation breakdowns on the electrical equipment of the locomotives, due to condensation when the locomotive passed through the centre of the tunnel, where the temperature reaches about 115 degrees Fahr. The locomotives at this point became drenched with moisture, but this is now avoided by keeping them warm over heated pits at the terminals, and the line is being operated with great success.

Some very powerful direct current locomotives are in use on the Pennsylvania Railway for hauling the main line trains from their New York terminal station to Newark, a distance of 12 miles. The locomotive is built in two sections, each having a symmetrical running gear and being joined at the middle with a permanent coupling. Each section carries one motor of 1,250 H.P. giving the locomotive a capacity of 2,500 H.P. Power is transmitted from the motor armature shaft to the wheels by means of cranks and connecting rods. These locomotives are capable of starting a 550-ton train on a 1 in 50 grade, and the normal speed with a similar load on the level is 65 miles an hour. The following are particulars of these locomotives :—

Wheel arrangement	4–4–4–4.
Total rated H.P. (hourly rating) ..	2500.
System and Voltage	D.C. 650 volts.
Diameter of driving wheels	72 ins.
Diameter of guiding wheels	36 ins.
Length overall	64 ft. 11 ins.
Total weight	149 tons.
Weight of electrical equipment ..	57 tons.
Weight of mechanical equipment ..	92 tons.
H.P. per ton weight of locomotive ..	16·8 tons.

These are up to the present the only D.C. locomotives using cranks and side-rod transmission. According to the *Times Engineering Supplement* of September 11th, 1912, thirty-three of the above locomotives were operated during that year on the Pennsylvania's New York terminal district with a total delay of only 13 minutes, which was attributable to the electrical apparatus. The total mileage run was 909,238, and in the case of one locomotive the mileage amounted to 56,000. The centre of gravity of these locomotives is 64 ins. above the rail level.

Side-rod locomotives, although having found considerable favour on the Continent for high-speed passenger work, are heavy and expensive, owing to the low speed of the motors, and do not show up well in regard to weight and efficiency when compared with the gearless locomotives of the New York Central. For medium speed passenger and freight services geared locomotives are undoubtedly the right thing.

To whatever stage of development electric locomotive design may lead, it has been demonstrated beyond doubt that the electric locomotive has set a standard for reliability and low cost of operation hitherto unapproached by the steam engine—a fact amply proved by Mr. Wilgus' figures in his paper on the Electrification of the Suburban Zone of the New York Central Railway read before the American Society of Engineers.

For a considerable time steam and electric trains operated side by side on the New York Central Railway and this afforded an unexampled opportunity for a true comparison of costs of operation.

Mr. Wilgus said :—

> "Although the fixed charges and depreciation of the electric locomotive are higher than those of the steam, owing to the greater first cost, the nett result is in favour of the electric locomotive, due to lower costs for repairs and maintenance. These results are based on actual observations of the steam locomotive covering a period of several years and of the electric locomotive for two years on the experimental track near Schenectady and one year in the New York zone. The reasons for the lower cost of repairs on the electrical machine are the simplicity of construction and the minimum number of mechanical parts. The results of these observations show that under the New York Central conditions the electric locomotive has the following advantages over its steam rival :—
>
> 19% saving in locomotive repairs and fixed charges.
> 18% saving in dead time for repairs and inspection.
> 25% greater daily ton-mileage.
> 6% saving in locomotive ton mileage in hauling service.
> 11% ,, ,, ,, switching ,,
> 16% ,, ,, ,, road ,,
> 12% nett saving cost in hauling service.
> 21% nett saving cost in switching service.
> 27% nett saving cost in road service."

CHAPTER VI.

As stated in Chapter I. motor car trains have rendered such great service to electric traction by giving the electric train enormous advantages over that operated by steam that it is necessary to consider them somewhat fully.

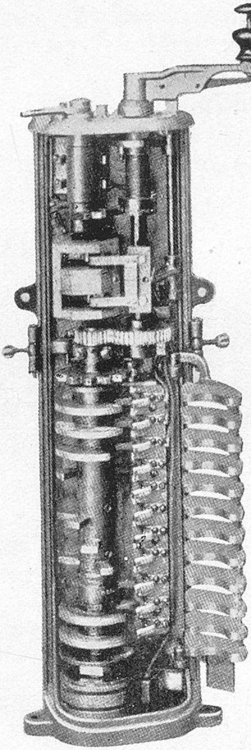
Mr. Aspinall said before the International Railway Congress at Washington in 1905 when speaking of motor car trains :—

> "Every time a locomotive train comes in and goes out you have four platform operations and eight signal operations. First of all the train comes in ; then a locomotive follows it, that is two ; then the train goes out, that is three ; then the locomotive which brought it in goes out, that is four platform operations, which means eight signal operations. The electric motor train comes in, that is one ; the motor-man goes to the other end of the train, and the train goes out, that is two. You have only two platform operations, and four signal operations. The result is that by using motor car trains instead of locomotives you double the capacity of your terminal accommodation."

In the early days of electric traction it was found that the seating capacity of the travelling unit was not large enough. The travelling unit consisted of a motor car such as was found on the early electric tramways. Soon trailers were attached to the motor car, but it was found that although the seating capacity was increased the schedule speed was decreased owing to the extra weight hauled. Then followed a period when two mechanically coupled motor cars were used, each operated by a separate motor-man, but the increased cost of the train crew, and the difficulty of operating each motor car so that the motors were working in synchronism, soon put a stop to this practice.

Several experiments were made to overcome the difficulty, but it appears that they were not successful, for when in 1896 the plans were made for the first electric trains in Chicago the General Electric and Westinghouse engineers reported that the multiple unit motor car train scheme was impossible, and even if technically possible could not be practicable.

Mr. Sprague, however, after years of experimenting secured the adoption of his scheme in 1898 by the South Side Elevated Railway of Chicago.



Master-Controller.

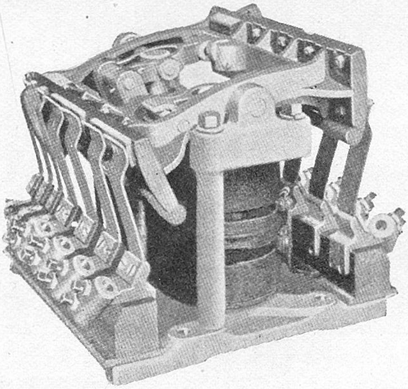
Multiple unit or motor car train operation which is now in use all over the world is defined by Sprague as follows :—

" A semi-automatic system of control which permits of the aggregation of two or more transportation units, each equipped with sufficient power only to fulfil the requirements of that unit, with means at two or more points on the unit for operating it through a secondary control and a train line for allowing two or more of such units grouped together without regard to end relation or sequence, to be simultaneously operated from any point in the train."

Although the multiple unit control apparatus is comparatively complicated, the entire system is as perfect as a clock, and in operation is extremely reliable.

The Sprague multiple unit control consists essentially of two parts :—

First—A series-parallel motor controller consisting of a number of electrically operated switches called contactors and an electrically operated switch called the reverser. The contactors make the different electrical combinations of the motor and regulate the starting resistance in circuit with them.

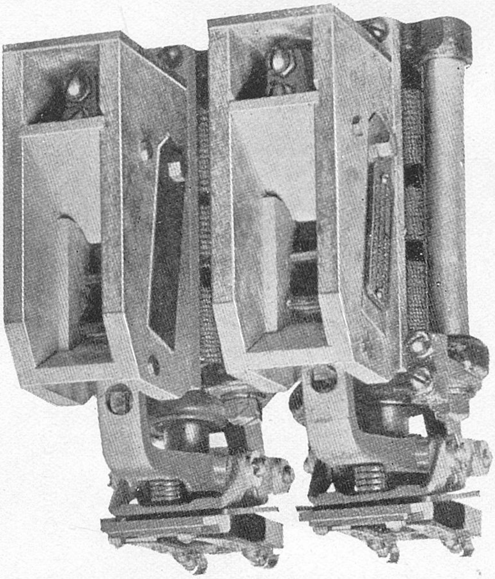


Motor Reverser.

Second—A master controller situated in the driver's cab of each motor car (or trailer if necessary) which operates electrically and from any distance, the contactors and reversers controlling the motors.

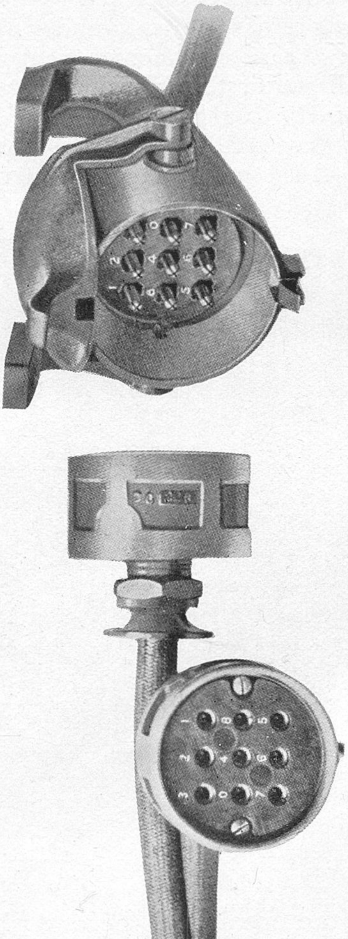
A cable makes electrical connection between each master controller and the contactors, and runs the entire length of the train with suitable couplers for making the necessary connections between the cars.

The master controller is operated by hand, and the motorman therefore has the train under his immediate control, and in a case of emergency can utilize the full power of all the motors in either direction. From the position of the controller handle the motorman knows exactly the various electrical connections of the motors on all the motor cars in the train.



Contactors.

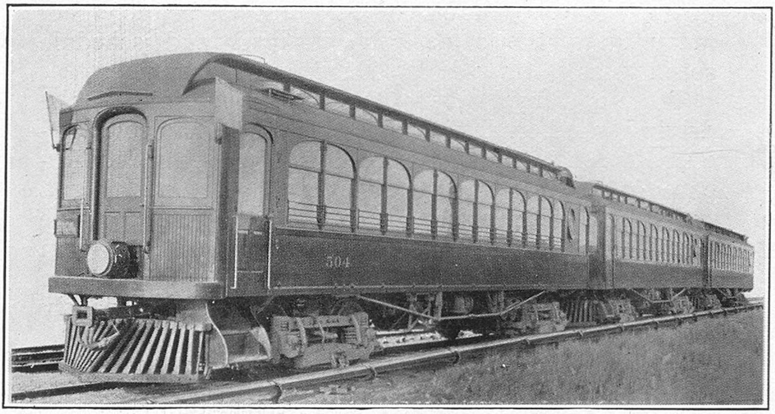
The handle of the controller is provided with a device known as the "dead man's" handle. This device ensures the opening of the control circuit and the shutting off of all power from the train, as well as the opening of the air valve which will apply the brakes on all the cars in the train when the motorman releases the controller handle. This affords complete protection to the train in the contingency of the motorman being taken suddenly ill at his post, and



Control Cable Connectors from Car to Car.

consequently renders it unnecessary for a second man to be kept in the driver's cab.

All current for the operation of the contactors on each of the cars on the train passes through the single master controller under the immediate control of the motorman. Should the train divide into two parts owing to an accident the current in the control circuit of the rear part is immediately cut off without in any way affecting the motorman's control of the first part.



3-Car Electric Train, West Shore Railroad.

The operation of the corresponding contactors on each car being simultaneous with the movement of the master controller handle ensures at all times similar electrical connections of resistances and motors on all cars. This results in equal and simultaneous acceleration of all motor cars, and prevents surging between vehicles during the period of acceleration, which is of importance from the point of view of comfort to passengers.

A great advantage attending the use of motor car trains is the great flexibility in making up. Cars can be added to or taken from the trains to suit the amount of traffic in a fraction of the time necessary with steam ; consequently advantage can be taken of this facility in making up to arrange that the length of trains shall at all times be proportionate to the traffic to be carried.

Starting at the time of least traffic one can operate the smallest allowable unit at intervals ; then, as traffic increases, the time interval between the trains can be shortened up to the minimum permitted by the signalling arrangements. As the flow of traffic further increases, the size of train unit can be increased, maintaining the same time interval and schedule speed so as to provide for the maximum traffic.

There is a fixed relation between the weight on the driving wheels and the total load to be hauled whatever the length of train, and it is a matter of indifference to the motorman whether he is operating a train consisting of one car or ten cars, for the characteristics are in each case the same. This is in striking contrast with steam trains, where a variation in the load to be hauled by a given engine obviously affects the acceleration possible.

The energy consumption with electric motor-car trains is practically proportional to the number of coaches run ; while in the case of a steam train this is not the case, as the locomotive itself constitutes a fairly large percentage of the total train weight.

In motor-car trains each unit is lighted, heated, and braked independently, and has independent movements ; consequently inspections, repairs, and train combinations are greatly facilitated, while locomotive shunting at terminal stations is entirely abolished. This feature can be of great utility for working branch lines, as a train can be split into two or more sections, each proceeding on a branch line under its own power, re-combining on the return journey as a single train on the more congested part of the line and thus saving block spaces and signalling effort.

But there is one disadvantage with motor-car trains. In times of heavy holiday traffic they cannot be used for main line purposes without separating the trailers from the motor cars. The latter, of course, cannot be hauled economically by steam locomotives, whereas the present steam suburban rolling stock can be pressed into service on main lines during heavy holiday traffic and is of great assistance. To obviate this disadvantage it might be advisable to electrify the main lines where traffic is most dense.

The making up of trains, so far as electrical features are concerned, is as simple as coupling up a Westinghouse air pipe. No main currents are carried from car to car—only small currents through jumper connections—and the electrical combinations are effected automatically however the trains are made up.

It is of interest to note that while there are several multiple unit control systems on the market to-day, and the design of the mechanism has been radically changed and materially improved, the fundamental principles of operation defined by Mr. Sprague and incorporated in his original apparatus have finally been adopted in their entirety by all manufacturers of multiple unit control apparatus.

The operation of multiple unit motor-car trains is extremely reliable, notwithstanding the complications of controllers and contactors. The use of several motors on a train provides a large margin of reserve in case of accident to an individual motor.

On the New-York Central the multiple unit motor car trains traversed in 1908 3,500,000 miles with a total train delay of 830 minutes, or one minute delay per 4,210 miles travelled. Train delays were about equally divided between electrical and mechanical causes.

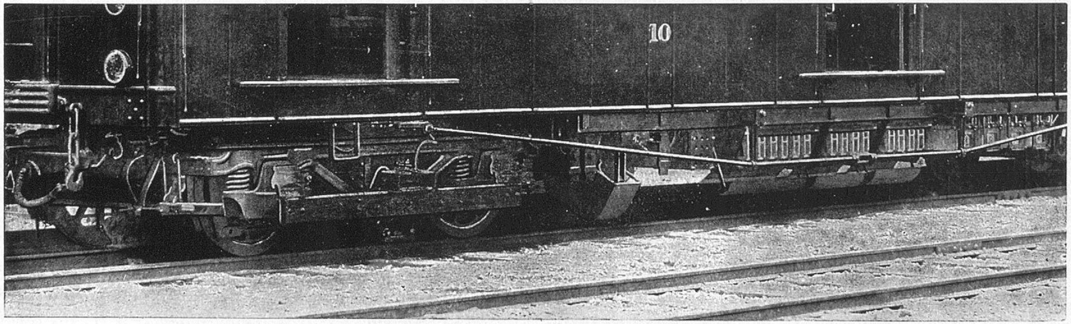
On the District Railway the delays from all causes (electrical and mechanical) for the month of December, 1909, averaged about 33 seconds per day per train and only 2½ seconds per day on the London Underground tubes. All these lines are of course operated with motor-car trains.

On the District Railway each motor car is equipped with two 200 horse-power motors, and one trailer and one motor car form a unit. An eight-car train consists of four motor cars and four trailers.

The longest multiple unit trains are operated on the New-York Subway, having ten coaches, seven motor cars and three trailers. These trains weigh about 415 tons and carry fourteen motors each of 240 horse-power, giving a total horse-power capacity of 3,360 per train.

By abolishing the dead weight of the steam locomotive the ton mileage is considerably reduced.

On the Lancashire and Yorkshire Railway during the first year of electrification the daily ton mileage was reduced some 8·5 per cent., notwithstanding the the fact that the service had been greatly increased and that 14 per cent. more passengers were carried.



District Railway Motor Car: View showing Multiple Unit Control Apparatus supported from Car Body.

CHAPTER VII.

Having reviewed the technical details of electric traction, we are brought to the economic side of the question. We shall now endeavour to show that, under certain conditions, electricity as a motive power is an invaluable factor in developing the traffic of a railway, and that, in comparison with steam, it has greater possibilities of making a large profit on the total amount of capital invested. The substitution of electric for steam traction presents, however, a most difficult problem, which can only be solved by scientific reasoning and technical judgment, for it must be proved beyond all doubt that the physical advantages of electric traction constitute a real and definite commercial value over existing conditions.

The problem of electrifying a steam railway may be divided into three cases: (1) the Doubtful, (2) the Feasible, and (3) the Unavoidable. In the first two the financial question is the more important, but in the third case a railway company is confronted (as a rule) with the absolute necessity for improvements in the traffic conditions at terminals, or the better negotiation of heavy grades and long tunnels approaching terminal stations.

Congestion at terminal stations has its origin in the first lay-outs of railways, a fact which was clearly recognised by the Royal Commission on London Traffic in a report issued in 1905, as will be seen by the following :—

> The next feature that is apparent is the large number of branches which have been thrown out by existing railways for the purpose of securing suburban traffic. The method usually adopted is to make a spur or branch from an existing railway to the district needing accommodation and not to make a separate line from a suburban district direct to a new terminus in London. This method has secured the result aimed at with the least expenditure of capital. It has much to commend it. It brings to existing railways additional traffic, which by strengthening their resources, enables them to add to their accommodation in other directions.

> But the method ceases to be advantageous when the final section of the approach to the London terminus becomes too crowded with trains. If too many branches are made, the train services which have to be run on the final approach lines to London become so numerous that the company are unable to deal with them on their approach lines and at their termini without costly alterations.

The traffic which causes the congestion is mostly due to the large number of people who travel daily between a great city and its suburbs. As the above report states, the congestion chiefly occurs at the final approach lines to the terminus, but beyond a certain distance from the terminal stations as lines bifurcate, the suburban trains become fewer and fewer and do not interfere so much with main line traffic.

If the main line traffic is in itself so large that the traffic density is high, electrification of this section is quite as feasible as electrification at terminal ends.

The capital cost of electrification and operating expenses can be very closely estimated; the most serious difficulty is to estimate the increase in receipts that would ensue from improved travelling facilities. No definite conclusion is possible in this direction, as there are so many considerations involved, but the experience of one railway may be used in making an estimate for another, due allowance, of course, being made for local conditions. In nearly every case the increased traffic due to electrification has exceeded first expectations. On the District Railway the passenger traffic increased 71 per cent. and the gross earnings 68·4 per cent., but for the moment we will defer going fully into the statistics of that railway, reserving a complete parallel table of steam and electric figures for a later stage. On the North Eastern Railway the passenger traffic increased in two years 24·5 per cent. and the gross earnings 17 per cent. The following, which deals with the North Eastern Railway, is a quotation from Mr. Harrison's paper read before the Institution of Civil Engineers :—

> Since the inauguration of electrical working the passenger load has steadily increased, and the present volume could not be dealt with by any other method without substantial increase of terminal accommodation.

At the February, 1905, meeting of the Lancashire and Yorkshire Railway shareholders, the chairman stated, in connection with the electrification of the Liverpool-Southport line, that the increase in traffic had "exceeded their most sanguine expectations." On the Mersey Railway the passenger traffic increased 92 per cent. and the total working expenses only 7·4 per cent.

Mr. Forbes, the general manager of the Brighton Railway, has stated before the Institution of Civil Engineers that on the South London line they carried in 1902 about eight million passengers. In 1909, owing to tramway competition, the number of passengers had dwindled to 3¼ millions, but that year electric traction came into operation, and in 1910 the line had carried eight million passengers. Thus the whole of the five million passengers lost between the years mentioned had been recovered. The chairman of the Brighton Railway said on February 5th, 1913:—

> The average number of passengers carried each year on the South London line since electrification was over four and a half millions more than the number carried in the last year of steam working, or fourteen million more passengers during the whole period. The Victoria and Crystal Palace electrical services began eighteen months ago, and in that period there had been an increase of nearly four million passengers. The London Bridge and Crystal Palace services had been in operation for six months, but even in that time they had obtained an increase on this section of over 319,000 passengers.

Among the advantages of electric traction for suburban services may be mentioned the following:—

(1) High schedule speed.
(2) More frequent service.
(3) Increased capacity of terminal accommodation.
(4) Increased earning capacity.
(5) Greater flexibility in making up trains.
(6) Many incidental economies which can be effected due to a cheap supply of electric power.

The principal cause of the increased traffic capacity which electric traction confers is the more rapid acceleration of an electric compared with a steam train. We have shown how an increase in acceleration gave a higher schedule speed. The advantages of a high acceleration do not stop here, since the shortening of time of travel admits of more trains being run. Owing to the block system on railways it is impossible for trains to follow each other closely in the manner of tram-cars, and it is therefore of enormous importance that no train should occupy a block section for one second more than is necessary. Electric traction consequently increases the capacity of the line by admitting of a more frequent as well as a more rapid service. On all railways where electric traction has superseded steam the frequency of the service has been practically doubled without increasing either the number of tracks available or the terminal accommodation.

Mr. Aspinall in his Address to the Institution of Mechanical Engineers, referring to the Lancashire and Yorkshire Railway Electrification, said :—

> " To deal efficiently with the considerable goods traffic, as well as the numerous steam passenger trains, there were four lines of way from Sandhills Junction up to Seaforth and then two lines of way on to Southport. On the length where four lines of way existed there were four passenger stations, each having four platforms with all the necessary waiting rooms, etc. All these platforms were required and were used in the days of steam trains. Although the frequency of trains has been more than doubled, the rapid acceleration and the increase in the average speed of travel has enabled the whole of the work, with the exception of one or two trains, to be done on two lines of way."

The increased capacity of a railway is probably the most valuable economic result attained by the use of electricity, as a volume of traffic can be handled on two tracks which would possibly require four tracks with steam traction. During the steam days the most crowded part of the District Railway (South Kensington to Mansion House) carried a maximum of about eighteen trains per hour. With electric traction this figure has been raised to about forty-four trains per hour. The most remarkable thing is that with each increase in the train service the traffic grows. It is essential therefore that there should be a frequent service, and not only so: it should be sufficiently rapid to make it worth people's while to walk to and from a station rather than take other means of conveyance nearer to hand.

In a district where a steam railway has had its track paralleled by tramways running for some distance from the terminal of a great city electrification may produce two results. It may either bring back to the railway a large number of passengers who have used the trams and found they cannot put up with the great waste of time (which results from very slow speed and many stops due to congestion of traffic), or it may create an entirely new traffic, bringing a large increase of passengers to the railway without taking traffic from the trams. Referring again to Mr. Aspinall's address to the Institution of Mechanical Engineers, he says in regard to the electrification of the Lancashire and Yorkshire Railway :—

> "In 1907 all the lines leading to Aintree were electrified and trains run thereto from Liverpool *via* Kirkdale and *via* Marsh Lane. A very large traffic which was previously taken away by the Municipal Tramways, which run parallel with and not many yards from the electric line, has now come back to the railway."

We shall refrain from giving more examples, but it will be admitted that, in considering the electrification of a steam railway, it is misleading to obtain figures showing the likely profits to be derived from such an undertaking by merely compiling data of the cost of installation, its operating expenses, and the traffic receipts based upon the number of persons travelling at the time. A margin must be allowed in favour of electrification for the extra traffic the increased facilities will undoubtedly produce. The London Traffic Commission reported in 1908 :—

> Much has already been done by the railway companies, and the growth of population in the suburban districts shows how quickly the latter respond to improved facilities for locomotion. The provision of better means of access to London has an immediate effect. Houses spring up at once and land rises in value.

Again in 1909 the Commission stated :—

> Good train services have a powerful effect in promoting the development of residential districts. Examples of this are to be seen in the neighbourhood of Dollis Hill, between Willesden Green and Neasden, where the Metropolitan Railway have opened a new station, at Harrow where there is now a 10-minutes service of trains, at Wembley Park, at Golders Green, and in other directions.

Experience has proved that the amount of traffic increases approximately in proportion to the facilities given to the public, and that it is quite possible to create traffic in addition to providing for that already existing. It is the function of a railway, not only to attract the business community, but also to induce the patronage of people who, in the ordinary course of events, would either not travel at all or else use some other system of conveyance. This patronage can only be brought about by increased offers of comfort, frequency of service and speed.

Apart from frequency of service and speed, which no doubt form the chief attractions from the passengers' point of view, the following useful additions to the other advantages of electric traction must be borne in mind :—

(1) *General Comfort of Passengers.*—Cleanliness and improved ventilation made possible by the elimination of smoke and cinders are much appreciated by the public. Due to a cheap supply of electrical energy delivered to the train, electric lighting can be installed and maintained at a very low cost. Electric lamps and electric heating apparatus, effectively and conveniently controlled, can be placed in any desired position. These

additional comforts are factors of great importance in building up passenger traffic, especially when there is severe competition.

(2) *Reliability of Operation.*—An indispensable requirement to the success of a system for working suburban traffic is immunity from breakdown, for delays to a dense service are fatal. Modern electric railway apparatus, if chosen with regard to the nature of the service and maintained with care, leaves little to be desired. Comparison of train delays (from all causes both electrical and mechanical) before and after electrification upon the few roads which have been operating sufficiently long by electricity to guarantee the results which have been obtained, points to the conclusion that the electric service in some cases is more reliable than the steam.

The following results have been published by the Manhattan division of the Interborough Rapid Transit Company :—

	Steam from November, 1900 to March, 1901.	Electric from November, 1905 to March, 1906.
Average cars per train ..	3·8	5·3
Car Miles	18,527,773	25,482,081
Train Miles	4,588,000	4,810,000
Total delay in Minutes ..	8,258	5,970

Mr. Wilgus in his Paper on the Electrification of Suburban Lines of the New York Central and Hudson River Railway read before the American Society of Civil Engineers in March, 1908, has made the following statement :—

> "During two representative months the delays per 1000 locomotive miles between Woodlawn and the Grand Central Station due to locomotive failures were as follows :—
> New York Central Electric Locomotives, 1.2 minutes.
> New York Central Steam Locomotives, 2 minutes.

It may safely be said that the present operation of electric trains is very reliable, especially when one considers that on a very large electrified system in America, *viz.*: the West Jersey and Seashore Railway, the train detention in minutes due to motive power troubles is only 8·45 per cent. of the total train-minutes delay from all causes (See also Chapter VI., "The reliability of motor-car trains.")

The capital expenditure involved is perhaps the chief hindrance to the immediate general adoption of electric traction. The cost of electrification depends mainly upon (1) the density of traffic to be handled, (2) the length of route and tracks to be electrified, (3) the schedule speed, distance between stops, grades and weight of trains to be handled, (4) the system to be employed. These points settled, the total cost can be closely estimated. Electric traction enables us to improve very greatly upon the performance of suburban steam trains, but the greater the improvement the higher the capital cost and operating expenses.

In the conversion of a steam line to electric traction various outlays are often incurred which should not be charged to the capital cost of electrical equipment alone. Frequently when electric traction is introduced new rolling stock is built, station improvements and other works are carried out; and it is obviously unfair to include such items in the capital cost of an electrification scheme in cases where it is quite possible their provision would be necessary under any circumstances. The principal items making up the total capital cost of a scheme are the power house, transmission system (bringing the power from the generating station to train), and the electrical equipment on the trains. Figures relating to the cost of these items for another railway are no guide unless one is fully conversant with the local and exact operating conditions of the line to which they relate, but the capital cost varies roughly between the following limits :—

Power House ..	20% to 40%.	Average	30%	of total cost.
Transmission Lines, Sub-Stations and Track Equipment	35% to 55%.	,,	45%	,, ,,
Electrical Equipment on Rolling Stock	20% to 30%.	,,	25%	,, ,,

An item of special importance is the capital charge of electrification "per train mile." Taking interest at 4%, the capital charges on some of the electrified lines were as follows :—

Lancashire and Yorkshire : 2d., excluding rolling stock, and 2½d. including rolling stock.

Mersey Railway : 4·3d. for the complete electrification scheme.

North Eastern : 1·93d., not including a power-house.

London, Brighton and South Coast (London Bridge—Victoria section) : 5d., not including a power-house.

District Railway : 4·5d., not including a power-house.

It appears, therefore, that the capital charges vary enormously, but this again may be on account of several costly alterations being included in the capital cost of the electrification scheme.

If a cheap supply of electrical energy can be procured from an outside company the capital cost is, of course, considerably reduced, and there is no doubt that the availability of a cheap supply of power would act as a great stimulus to electrification.

Operating Costs : It is common belief that one of the chief objects of electrification is to reduce working expenses, and should a large saving not be effected in this direction, the scheme is taken to have failed in its mission. If an electrification scheme is properly carried out, it should effect large economies in operating expenses (especially if these be considered "per train mile"), but its primary duty is not altogether to accomplish this—rather is it to increase the earning capacity of a railway. Whether it be an electric or steam railway that is concerned, it is more practical to augment the nett revenue by increased gross earnings than by decreased operating costs. Where electric traction is in operation on a one-time steam railway, the train mileage, as a rule, is greatly increased. The result is a reduction in the average cost per train mile, even should there be no reduction in the total cost of operation. It must be remembered, when dealing with operating figures of steam and electric trains, that the latter are placed at a great disadvantage, as we are comparing trains running at vastly different speeds. Electric trains work, of course, at very much higher schedule speeds than steam trains, and this increase cannot be obtained for nothing either by steam nor by electricity. The higher the schedule speed, the greater will be the power consumption, and this rule applies to all systems of locomotion.

It is, of course, possible to electrify a railway in such a way as to leave trains running at the same speed as that at which they formerly ran, but most of the advantages of the installation would be sacrificed, although working expenses would be very low.

Railway accounts are generally grouped under the following headings :—

Locomotive Power.
Maintenance of Way and Works.
Repairs and Renewals of Carriages and Wagons.
Traffic Expenses.
General Charges.
Rates and Taxes.

The first four items amount approximately to 82 per cent. of the total costs, and are the only ones seriously affected by the method of traction used.

The main items affecting locomotive costs are fuel, wages of drivers and firemen, repairs to engines, oil, water, and engine stores. There is a considerable saving in fuel costs with electric traction, even where schedule speeds have been increased by as much as 35 per cent. On the Manhattan Elevated Railroad in the days of steam haulage, it was found that under the most favourable conditions one pound of coal could only produce 2·23 ton miles or 1·50 ton miles when weight of cars only was taken into account. The advent of electric traction enabled 1 lb. of coal (burned at the power house) to produce 3·85 ton miles, notwithstanding the fact that the schedule speed had been raised some 35 per cent. and that the coal burnt at the power house was of a lower grade and therefore less expensive than that used by the steam locomotives. Mr. Murray, in a paper referring to the New York, New Haven and Hartford Railway, in 1907, stated before the American Institution of Electrical Engineers :—

> By far the most interesting feature of the investigation is to find that by actual operation the saving in coal for electric passenger operation as against steam for the same service is just 50 per cent.

On April 7th, 1911, he stated before the same institution :—

> Suffice it to say that the two great departments of economy lie in the saving of fuel and repairs to rolling stock equipment.

Mr. Shaw, in a paper read before the Institution of Civil Engineers in 1909, made the following statement in connection with the Mersey Railway :—

> The comparison indicates that with electric traction 1 lb. of coal costing 8s. 9d. per ton will move one ton of load 2·29 miles at an average speed of 22¼ miles per hour, whereas with steam traction the same weight of coal costing 16s. per ton would move the same load 2·21 miles at an average speed of 17¾ miles per hour.

In the same paper Mr. Shaw published the following interesting figures relating to the coal consumption on the Mersey Railway under steam and electric traction :—

	STEAM.	ELECTRIC.
Total coal per annum, in tons	8,874	13,114
Cost per ton	16/-	8/9
Total cost	£7,100	£5,246
Consumption per train mile, in lb.	64·0	35·5
Consumption per ton mile, in lb.	0·453	0·436
Fuel costs per train mile, in pence	5·49	1·67
Fuel costs per ton mile, in pence	0·0358	0·0202
Increase in schedule speed	—	25·5%

Mr. Aspinall has stated before the Institution of Civil Engineers that in the old days of steam traction some of the trains on the Liverpool-Southport line consumed 60 lb. of coal per mile, but taking out the whole of the figures for one year the coal used was 48·28 lb. per mile. As the coal was then purchased at 11s. 3d. per ton, the fuel cost worked out at 2·91d. per train mile. The Lancashire and Yorkshire Railway increased the speed of their trains 50 per cent. when electric traction was introduced, which is more than any other railway has ever done before, so that the electric service between Liverpool and Southport may be considered as the fastest service of its kind in existence. In spite of the great increase of speed, the fuel consumption at the Formby Power House works out at 49 lb. per train mile, and as the probability is that a cheap kind of coal is used, the fuel costs, even in this exceptional case, do not exceed those of the much slower steam trains. Mr. Aspinall has also stated that the steam trains consumed from 80 to 100 lb. of coal per train mile when trying to keep time with the electric trains, which consumed 49 lb. only. If the electric trains had been run at the same speed as the steam trains ran before electrification took place, the coal consumption would have been some-thing like 26 lb. per train mile at the power house instead of 48·28 lb.

In order to realize fully the great economy effected in coal consumption with electric traction it would be well to compare the coal required to produce one horse-power-hour at the rim of the drivers. Suburban steam locomotives consume when running about 4·5 to 5·0 lb. of coal per indicated horse-power-hour. Assuming 20 per cent. to account for coal when the engines are not actually engaged in hauling trains and rating the average mechanical efficiency of the engine at 80 per cent., we obtain a coal consumption of about 7 lb. per horse-power-hour at the rim of the driving wheels.

An average figure obtained at a modern power house is a coal consumption of 2·5 lb. per kilowatt hour. Let the efficiency of transmission from generator to the train be 80 per cent. and the efficiency of the electrical equipment on the train 70 per cent. (average figures obtained in practice). This gives an over-all efficiency from power house to rim of drivers of 56 per cent. and a coal consumption of 4·5 lb. per kilowatt hour (1 kilowatt hour equals 1·34 horse-power-hour), or, say, 3·4 lb. per horse-power-hour. Therefore, in order to produce one horse-power-hour at the rim of drivers, 3·4 lb. of coal are required when using electric traction and 7 lb. when using steam. Electric traction thus shows in this respect a saving of 51 per cent.

It may be fairly assumed that where average quality coal is used for steam locomotives about 12s. 6d. per ton is paid delivered on tender. Now a much cheaper quality coal can be used in a power house, costing about 9s. per ton. Based on these rates, the relative difference in the cost of coal at the rim of drivers is 65 per cent. in favour of electric traction. This comparison strongly emphasizes the importance of a railway company being able to use a low grade coal.

The reasons making it possible to obtain this great fuel economy in a power house are based on the increased thermodynamic efficiency. The better utilization of heat is effected in (1) the boiler and (2) the steam engine. A stationary boiler is not limited for room, and consequently the heat in the waste gases can be utilized more effectively by means of feed water heaters and economisers. The loss of heat by conduction and radiation is also less in a stationary boiler than is the case with a locomotive boiler. For stationary boilers the fires can be fed with mechanical stokers which improve the combustion to an extent that results in practically no smoke being produced. Furthermore, as we have seen, the lowest qualities of coal and waste products can be burned under suitably designed boilers. As regards reciprocating steam engines, it may be mentioned that they consume less steam if the degree of expansion is increased. Condensing, which cannot be satisfactorily applied to locomotives owing to the great amount of extra machinery and water required, is a very important factor in a power house, as it is instrumental in greatly increasing the range of temperatures between which the engine works. The low steam consumption of the steam turbine is chiefly due to the fact that it can use steam expanded beyond the limits practicable in reciprocating engines. This great range of temperature is obtained by superheating and highly efficient condensing. Superheating is also used with great success on main line locomotives, but it will be very difficult, if not impossible, to apply it effectively to suburban steam locomotives making frequent stops, as there is not sufficient time between stops to get the steam fully superheated. The superior efficiency of a modern power house is self-evident.

Quite recently Mr. Ferranti has obtained some remarkable results with a steam turbine designed by himself. In this turbine the steam is superheated, and after the first expansion (and whilst it is still superheated) the steam is re-superheated before doing its work in the second stage of the turbine. After this it is exhausted in a superheated condition through a regenerator to the condenser. A turbine of 5,000 horse-power of this type has now been running for some time, and when tested at a load of two-thirds full power has only consumed 7 lb. of steam per horse-power hour; while, from many tests already made, it appears that such a turbine under full-load conditions will take less than 6 lb. of steam per horse-power-hour. Hitherto the best steam turbine has taken about 10 lb of steam per horse-power-hour, so it will be seen that we are at the threshold of still further developments which should reduce the present coal consumption of power houses by about 40 per cent.

The enormous increase in the price of coal bears heavily on the railways; and, as time goes on, this question of cost will become more and more acute. In 1893 steam coal in the North of England was quoted on the average 8s . 6d. per ton, while to-day the best steam coal fetches about 15s. 6d.

One of the advantages of electric traction which has not been sufficiently emphasized is that the exact performance and condition of locomotives, motor cars, and all elements of the system are known at any moment. With steam traction one has no clear knowledge of the conditions of the moment, such, for instance, as whether the locomotive is efficiently loaded or working as economically as possible, and one can only ascertain these conditions by elaborate tests—which, as a matter of fact, are seldom made. Thus the exact directions in which one can expect to effect economies are more easily ascertained, and responsibilities for expense are more readily fixed, under electrical working. The rating and performance of a steam locomotive are arrived at mainly "on authority" based on a few tests taken from time to time, and as these take no cognisance of the actual commercial conditions under which the locomotive works, they are of comparatively little value.

Again, as stated in Chapter VI., only the services of one motorman are employed on an electric train, as compared with those of a driver and fireman on a steam train; and this, of course, represents a considerable saving in cost of labour. Again, as the rolling stock is more efficiently employed and is mobile for the greater part of its time, wages per train mile are reduced to a minimum. There is a considerable saving in oil stores and water—items which appear very prominently in the accounts of a steam locomotive. A steam locomotive has many moving parts which require lubrication: these parts are absent in an electric locomotive or motor-car. Moreover, with steam turbines in a power house, lubricating oil is re-used over and over again. There is also a large saving in water, as in a turbine power house the condensed water is also used repeatedly; consequently cost of water practically disappears with electric traction.

And then again, the cost of maintaining rolling stock and electrical equipment is less than the corresponding costs on a steam system. A fact which must be taken into consideration when comparing the maintenance of rolling stock and locomotives on steam and electric railways is that it is not feasible to take the exact equivalents of the two systems of traction, as under the multiple unit electric working the motor car not only takes the place of a locomotive but also acts as a passenger carrier. Less rolling stock is required to do a greater amount of work, which is a great economic advantage. When the Liverpool-Southport line was operated with steam, 30 locomotives and 152 cars (providing 5,084 seats) were required, this number including the necessary percentage under repair. The number of vehicles required to work a greatly increased service under electric operation over the same route and length of line is 38 motor cars and 53 trailers with a seating capacity of 5,814.

According to Mr. Aspinall, the average number of miles run per annum per steam locomotive on the Lancashire and Yorkshire Railway amounted to 20,000, whereas the electric motor-car or locomotive will run from 50,000 to 60,000 miles per annum. This is, of course, due to the fact that much less time is spent in repairs and inspection, and that no time is wasted in getting up steam and taking in coal and water. Greater locomotive and car mileage per day raises the value of railway investments in rolling stock and tracks. The figures for the Mersey Railway are :—

Steam Locomotives ..	17,274	miles per annum.
,, Coaches ..	22,672	,, ,, ,,
Electric Motor Cars ..	48,064	,, ,, ,,
,, Trailers ..	36,453	,, ,, ,,

On the New York, New Haven line, the electric locomotives cover on an average a distance of 210 miles per day. The steam locomotives on the same section ran, on an average, 158 miles per day.

On the Mersey Railway the cost of maintaining rolling stock under steam was 3·47d. per train mile: with electric traction it is 1·67d., a decrease of 52 per cent. The annual cost of maintaining a motor car is, however, somewhat more than the maintenance of a steam locomotive, but owing to the greater number of miles run per annum by the former the cost per mile run is considerably less.

The maintenance and repair costs of the District Railway's original electric locomotives (two of which, coupled together, hauled a nine-coach L. & N.W train more efficiently than any steam locomotive had ever done) amounted to ·5d. per mile. That service has been discontinued, and the locomotives are now employed in hauling the heavy corridor trains of the Tilbury line from Barking to Ealing ; the maintenance cost of this service has been given as 1d. per train mile for two locomotives coupled together, while the average cost of maintaining a steam locomotive in England, according to the Board of Trade Returns (1911), is about 4·2d. per train mile. On the New York Central the cost of repairs per locomotive mile amounted to 7·67 cents in 1911 for steam and 3·19 cents for the electric locomotives, a saving of about 58%. On the Pennsylvania Railway repairs and maintenance of locomotives amounted per locomotive mile to 5·91 cents for the electric, 8·83 cents for the steam locomotives in the New Jersey division, and 11 cents for the steam locomotives over the whole Pennsylvania system.

The maintenance of the permanent way of electric railways works out in the majority of cases at a little more than the maintenance of the permanent way of a steam system, and in view of the higher speeds and increased services this is not surprising. Low centre of gravity in electric rolling stock (mentioned in Chapter V. on Electric Locomotives) is, in the opinion of Mr. Aspinall, the cause of rapid wear on rails at curves, but as this abnormal rail wear has not been experienced in America and on the Continent it is perhaps a moot point whether our English track construction is altogether well adapted to electric rolling stock, although the trouble does not extend to every electrified railway in England. Careful comparisons have shown that the rails on the Mersey Railway have proved even more durable under electric traction than was the case under steam operation. The total cost per annum of maintaining a mile of double track on this railway has amounted to £526 with electric traction, as against £875 with steam, the average life of rails being 6·6 and 6·45 years respectively. Commenting upon the North Eastern Railway electrified lines in a paper before the Institution of Civil Engineers, Mr. Harrison said :—

> It is more difficult to ascertain the cost of increased wear on crossings, curves, etc., nor could any assumption be justified until experience has been considerably extended. In any case it would not be fair to debit electrical working with the wear due

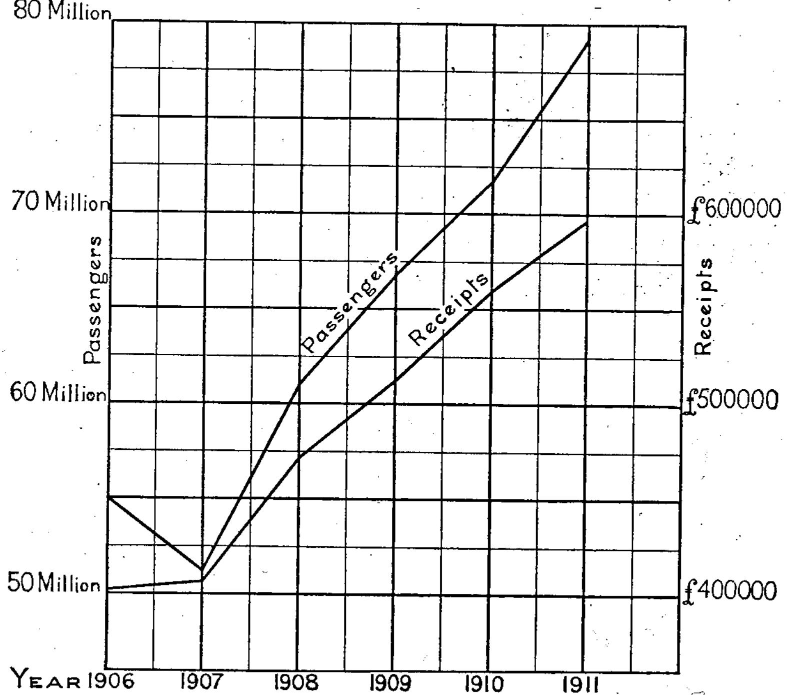
> to the rapid acceleration obtained, as without this acceleration the increased schedule speed would not be possible and steam locomotives for this acceleration would, owing to the increase of weight, be equally, if not more severe on the track. Although the foregoing remarks would indicate some increase in the permanent way maintenance by the introduction of electrical working, it must be borne in mind that substantial economies in track work have been rendered possible in other directions.

In reference to the West Side Elevated Railroad of Chicago, Mr. Brinkerhoff has stated before the Institution of American Electrical Engineers :—

> The fear that renewal of track, frogs, switches, etc., might, after a certain period, become expensive has not been realized after ten years of constant heavy service. At the same time the service has been immensely improved in frequency and speed.

On the London Underground tubes, which were specially laid out for electric traction, no serious rail wear has taken place, but on the District and Metropolitan Railways the rail wear on curves has been somewhat acute. This trouble has recently been considerably diminished by the adoption of Sandberg Silicon steel rails, which are harder than the ordinary rail and last much longer, notwithstanding the great increase in the number of trains. There has been recently introduced into America a titanium steel rail also, which is said to have a much longer life than the ordinary steel rail and costs very little more. The New York Central and other railways have already adopted this rail, but no figures have as yet been published in regard to wear. There is no doubt that at curves and crossings on electric systems the maintenance of the rails becomes greater as the axle mileage is increased, but as regards the straight track no definite opinion can yet be formed. On the District Railway the maintenance of way and works has increased about 95 per cent. under electric traction, but the cost per train mile for the same item has decreased from 3·29d. under steam to 2·87d. under electric traction. Traffic expenses remain practically the same in spite of the enormous increase in train mileage. This, of course, is due to the fact that considerably less rolling stock is required for equal services, as it is more efficiently utilized. On the District Railway the traffic expenses were reduced from 8·97d. per train mile under steam to 2·78d. under electric traction, while on the Mersey Railway the figures were 14·50d. and 6·35d. respectively. On the authority of Mr. Aspinall, again, it is possible, with power produced at the generating station at 0·25d. per unit, to work a high speed electric suburban service for 9·5d. per train mile, including works costs for power house and sub-stations, operating costs of motor and electrical repairs, car repairs, guards and motormen's wages, lighting and heating of cars, the maintenance of the third and fourth rails, cables and all working stores. The cost per car mile under such conditions varies from 2·75d. to 3d., according to the number of cars run. As, however, a large and well-designed power house can produce power at a works cost of 0·2d. per unit, it is quite feasible to run a high speed suburban service at 9d. per train mile. Adding to this the conservative figure of 5d. per train mile for interest on the total capital expenditure of electrification at 4 per cent., we obtain a total of 14d. per train mile, which includes, besides the capital charge, locomotive power and rolling stock maintenance. According to the Board of Trade Returns (1911) the average costs for steam locomotives and rolling stock in Great Britain amount to 15·70d. per train mile. An important point to be remembered is that the expense of working suburban train services around London is far greater per train mile than the average for the whole line as given in the Board of Trade returns, owing to short sections, shorter hours of labour and higher rates of pay. Heavy train loads and frequent stopping result in increased coal consumption and shorter mileage worked by engine-men. Mr. Gooday, in his evidence before the Royal Commission on London Traffic, March, 1904, estimated that the additional cost amounted to some 21% of the average cost as given in the Board of Trade returns; he considered this rather under than over the actual figure.

Let us now examine the financial results obtained on some of the electrified railways. The figures which follow have been compiled from various sources—principally from half-yearly railway reports, information given at half-yearly meetings, etc.



Curves illustrating the increase in passengers
and traffic receipts of the Metropolitan District
Rly during the period of Electrical operation

(The decrease in passengers in 1906 was due to the opening of the "Piccadilly" tube).

Fig. 19.

DISTRICT RAILWAY.

	YEAR 1904. LAST YEAR OF STEAM OPERATION.	YEAR 1912. ELECTRIC OPERATION.	INCREASE OR DECREASE.
Gross Earnings	£410,189	£690,910	+68·4%
Passenger Receipts ..	£366,392	£652,670	+78·2%
Number of Passengers ..	50,331,397	86,003,149	+71·0%
Total Working Expenses ..	£229,368	£290,061	+26·5%
Ratio of Working Expenses to Gross Earnings ..	55·8%	42·0%	—13·8%
Passenger Train Miles (Total on District Railway) .	1,475,958	4,080,358	+176·0%
Average Receipts per Passenger	1·75d.	1·82d.	+0·04d.
Nett Revenue	£180,821	£400,849	+121·8%
Total Working Expenses per Train Mile	35·6d.	18·6d.	—47·7%

	PER TRAIN MILE. STEAM, 1904.		PER TRAIN MILE. ELECTRIC, 1912.		DECREASE.
Way and Works ..		3·29d.		2·87d.	12·7%
Locomotive Power or Electric Train Working	8·30	10·42d.	5·74	7·82d.	25%
Rolling Stock Repairs and Renewals	2·12		2·08		
Traffic Expenses ..		8·97d.		2·78d.	89%
General Charges		2·97d.		1·32d.	55%
Total Working Expenses		35·6d.		18·6d.	46%

Approximate Capital Cost of Electrification (excluding Lots Road Power House)		£1,850,000
Interest at 4% on Capital Cost per annum	£74,000	
Annual Power House Charges ..	£34,300	
TOTAL CAPITAL CHARGES DUE TO ELECTRIFICATION	£108,400	
Nett Revenue in 1912 after deducting Capital Charges..		£292,549
Nett Revenue in 1904		£180,821
Increase		61·8%

	1903. Steam Operation.	1912. Electric Operation.	Increase.
Total Capital expended ..	£10,012,997	£12,648,374	26·3%
Revenue	£167,883	£366,549*	
Interest on Capital ..	1·67%	2·9%	73·7%

* Lots Road Power House charges deducted from Nett Revenue.

NORTH EASTERN RAILWAY.

The following figures were given at the half-yearly meeting in February, 1906:—

	Half-Year Ending 1903. Steam Operation.	Half Year Ending 1905. Electric Operation.	Increase.
Gross Earnings	£129,000	£151,000	17%
Running Costs	£42,761	£47,779	11·5%
Costs per train mile ..	14·5d.	6·75d.	—
Passengers carried ..	2,844,000	3,548,000	24·5%
Nett Revenue	£86,239	£103,221	19·8%

Cost of Electrification has been given at £244,000.
Interest at 4% is £4,880 per half-year.
Nett Revenue for half-year under steam £86,239
Nett Revenue for half-year under electric working after taking care of capital charges at 4% .. £98,341

Increase .. £12,102 = 14%

MERSEY RAILWAY.

	Half-Year Ending 1902. Steam.	Half-Year Ending 1912. Electric.	Increase.
Gross Earnings	£29,470	£59,651	102%
Working Expenses ..	£28,081	£31,245	11·3%
Nett Revenue	£1,388	£28,406	1,950%
Total paid up capital ..	£3,167,563	£3,609,108	13·9%
Annual rate of interest earned	0·088%	1·57%	1,685%

Approximate Electrification Cost, £414,368.
Capital Charges for half-year at 4%, £8,288.

Nett Revenue for half-year under steam	£1,388
Nett Revenue for half-year under electric working after taking care of the capital charges at 4% ..	20,118
Increase ..	£18,730 = 1,350%

	STEAM.	ELECTRIC.
COST OF OPERATION :—		
Locomotive power per train mile ..	10·18d.	3·78d.
Repairs and renewals per train mile ..	2·89d.	1·56d.
Cost of carriage maintenance per train mile..	3·47d.	1·67d.
Maintenance of way and works per train mile..	4·31d.	1·68d.
Total train miles per annum ..	310,944	828,674
Total expenses per annum	£62,897	£67,442
Total expenses per train mile ..	48·5d.	19·5d.
Increase in schedule speed ..	—	25·5%

From the financial results given it will be seen that an enormous increase in train mileage was obtained for only a small increase in working expenses. On the District Railway an increase in train mileage of 176% was obtained, with an increase in working expenditure of only 26·5%; while on the Mersey and North Eastern Railways an increase in working expenses of only some 10% was sufficient to double the train mileage.

The over-all financial results obtained are extremely good, for, after allowing 4% interest on the capital cost of the electrification, the increase in nett revenue on the District Railway amounted to 61·8%, on the North Eastern 14%, and on the Mersey 1,350%, the last-mentioned result being, of course, due to abnormal conditions. On the Mersey Railway the nett revenue under steam working dropped from £6,074 to £1,388 in the last complete half-year of such working, while in the following half-year it fell to £216, but that period represents four months steam and two months electrical working. Under the electrical operation the nett revenue, starting at £216 rose to £28,406 for the half year ending 1912. The effect of electrification had been that, after paying interest on the additional capital, the nett half yearly revenue of the company has been increased by £19,902.

It will be noticed that on the District Railway the capital of the company was increased 26·3%, but the interest earned on the capital nearly 74%.

Another interesting result obtained is the great reduction in the ratio of working expenses to gross earnings under electric traction, which proves that the electric railways are highly efficient as regards earning capacity.

Similar results have been obtained on electrified lines in other countries. The passengers on the Manhattan Elevated (New York) increased in number 46 per cent. after three years of electrification, while the proportion of working expenses to receipts was decreased from 61% to 46%. The nett result, after taking in consideration the increased capital charges, shows an increase of 15 per cent. in nett revenue.

Electric traction on suburban services does not diminish total operating expenses, but for the same cost a much better service can be given. For fairly dense services having a good all-day traffic it has been clearly shown that an electric service can be given with an increase in schedule speed of 25% and in train miles of 30%, and, when all the capital charges at 4% due to electrification are included, the total costs will not exceed those of the superseded steam services.

Mr. Merz, in his report on the electrification of the Melbourne Suburban Railways, showed that with an increase in schedule speed of 31 per cent., and in train miles of 29%, the saving in annual operating costs would, after paying 4% interest on the capital expended and providing the necessary sinking fund, amount to £20,174 without allowing for any increase in traffic.

CHAPTER VIII.

So far we have only dealt with suburban services, which are generally looked upon as the only field in which electric traction can be economically employed. Main line electrification, with the exception of sections where local conditions, such as heavy grades or tunnels have made electrification a necessity, has received practically no consideration. It has been generally accepted by railway engineers that for the operation of express passenger trains steam haulage is more economical. It is, however, gradually beginning to be recognised now that, even for an infrequent service of express passenger and goods trains, the economies which can be effected in fuel expenses, and maintenance and repairs of locomotives and rolling stock, are considerable, and will in many cases be more than sufficient to pay the capital charges of the electrification costs. Once the suburban area has been electrified, the capital cost of the electrification per mile is rapidly decreased by main line extensions. Very little attention has so far been given to the handling of goods traffic by electric locomotives. The present method of operating goods trains on main lines calls for some comment, as goods trains, running at low speed, cause delay to all overtaking traffic, and for a considerable part of their time are held in refuge and other sidings to avoid other trains. This results in waste of fuel, high maintenance costs, waste of men's time and inefficient use of track, wagons and locomotives.

The chief advantages to be reaped by handling goods trains by electric locomotives would be firstly the hauling of longer and heavier trains at higher speeds, and secondly an enormous reduction in locomotive stand-by losses, which are very high in goods train services.

On railways where the mileage of goods trains constitutes a high percentage of the total train miles, the coal costs form, as a rule, a much higher percentage of the total operating expenses than on lines where the number of passenger train miles is the greater. This is chiefly on account of the very low load-factor of a goods locomotive, which is caused by the large amount of time wasted in yards and sidings for shunting purposes or waiting for fast passenger trains to pass. The amount of coal consumed by a locomotive under steam when standing idle is surprising: as much as 300 to 500 lb. per hour may be burnt. Firing-up requires 500 lb. of coal in small locomotives, 800 in medium and from 1,200 to 1,600 in the largest. As is well known, a steam locomotive spends a good portion of its time in the shops undergoing heavy repairs, while a good deal of time is wasted in the engine sheds, where boilers are washed, fire boxes and tubes cleaned, light repairs effected, etc. Below is an interesting table published by Mr. Kahler before the American Institution of Electrical Engineers; this represents the actual distribution of locomotive service for a section of a railway from 500 to 600 miles long.

	PASSENGER LOCOMOTIVES.		FREIGHT LOCOMOTIVES.	
	Per cent. of Total Time.	Days per Year.	Per cent. of Total Time.	Days per Year.
Time in shops..	22·4	82	28·2	103
Time spare	1·4	5	2·7	10
Time in engine house (having running repairs done, boilers washed, fire-box cleaned)	53·2	194	35·9	131
Time running to and from trains ..	1·6	6	1·1	4
Time in helper service	1·1	4	4·3	16
Time on road actually running ..	20·3	74	17·1	62
Standing on sidings, taking water, etc.	—	—	10·7	39
Totals ..	100	365	100	365

It will be seen that each passenger locomotive was actually on the road 74 complete days in the year, while each freight locomotive was on the road 62 days, of which period 39 days were spent in sidings, etc. An electric locomotive spends much less time in the shed, because a steam engine receives a thorough inspection after each run, while an electric locomotive runs about 1500 miles before an inspection is made. The electric locomotive has a longer life than the other, but owing to its first cost being greater the actual depreciation charge per locomotive is greater. As, however, the number required to handle a given traffic is much smaller than the number of steam engines in use, the total depreciation is generally higher for steam operation.

With the electric locomotive it is possible to develop a much greater horse-power per ton weight, and also not only to deal with a larger percentage of overload when needed, but do it more economically than is possible with steam. The Pennsylvania electric locomotives, in use in the New York district and described in Chapter V., are rated at 2500 horse-power, but can be overloaded up to about 4000 H.P. for 30 minutes continuously.

The physical characteristics of a railway, such as grades, curvature, etc., have a very important influence upon its operating expenses. A great deal of money has been expended in taking out curvature, and in reducing grades, in order to minimise operating expenses and move heavier trains at higher speeds.

On railways where the ruling grade is heavy the weight and speed of goods trains can, in most cases, be largely increased by using electric locomotives, owing to their capacity to supply great drawbar pulls at high speeds to an almost unlimited extent. A Mallet Compound having a weight of 316,000 lb. on the drivers can only exert, at a speed of 15 miles per hour, a tractive effort of 44,500 lb., and at 20 miles per hour, 38,000 lb.; while the Pennsylvania electric locomotives, which are designed for passenger work, exert, at 25 miles per hour, a tractive effort of 47,000 lb., having a weight of 197,000 lb. on the drivers.

Furthermore, any number of electric locomotives can be coupled together and operated as one unit with only one train crew. Unfortunately for the English railways, there are about half-a-million private traders' waggons about the country, and most of these would not withstand the pull required to handle 1,500-ton goods trains. However, a great deal could still be accomplished by increasing the present speed of our heaviest goods trains, especially in congested districts.

Briefly summarised, the advantages of hauling goods trains by electric locomotives are: Less cross hauling of coal, water and engine ashes; greater train weights at higher speeds, and consequently a decrease in train mileage; great saving in fuel expenses; increase in mileage of freight trucks; decrease in maintenance and repairs; and last, but not least, the express goods service so ardently desired by the public. Most of our goods movement takes place at night; consequently, in the case of lines already electrified for the passenger service, it would be an enormous advantage to utilize by night, as well as by day, power-house, sub-stations, transmission lines, etc. upon which capital has already been expended.

As early as 1903 the President of the Pennsylvania Railway stated in the company's annual report: "In order to prevent the increase in ton-mile cost, it is necessary to move freight trains faster in places where traffic is dense, and for such purposes the electric locomotive is most efficient."

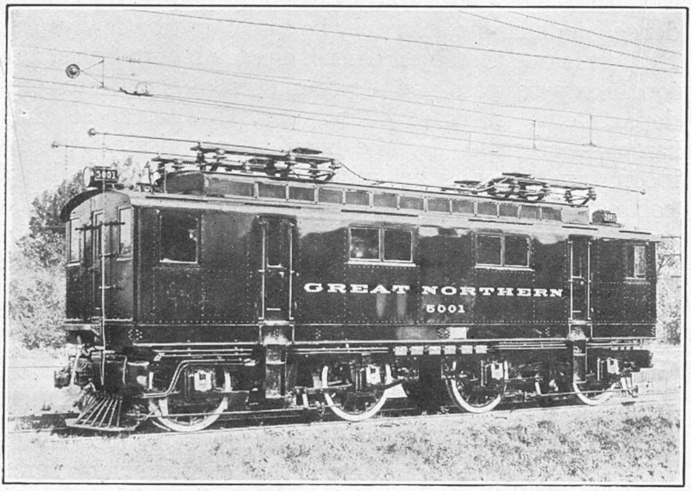
In England the North Eastern Railway have decided to electrify their line between Middlesbrough and Shildon, which carries a very heavy mineral traffic. The electric locomotives are to be capable of starting a 1,400-ton train load and of hauling it on the level at a minimum speed of 25 miles per hour. This experiment will, of course, be followed with interest, as it is the first introduction of electricity for handling heavy goods trains in this country.

It is worth while to note that Mr. Dalziel, one of the electrical engineers on the Midland Railway, has quite recently stated before the Institute of Electrical Engineers that in his opinion the coming of main line electrification, particularly on heavy-graded lines with dense goods traffic, can only be a matter of a few years. He points out that by means of electric locomotives, not too heavy to pass the requirements of the Engineer's department, trains of 40 wagons, as against 29 that can now be taken by the heaviest permissible steam locomotives, could be run on the Midland Railway between Derby and Manchester Ancoats, and this could be done with a reduction in running time, from 3 hours, 5 mins. to 2 hours, 1 min.—a saving of 35% in running time.

The capability of electric locomotives to take large overloads is of enormous importance on lines where, due to heavy grades, traffic is congested. In the Western States of America several mountain grade divisions of main line railways are now being electrified, while others have been actually in operation for some time. The economies which can be effected by electrification on such railways are enormous, while the traffic capacity is at the same time greatly increased.

One of the best-known mountain railways which has been electrified is that of the Cascade Tunnel in the States. The Great Northern Railway crosses the Cascade Mountains through a tunnel 2·6 miles long, having a ruling grade of 1 in 45·5. This tunnel is the limiting feature to the capacity of the railway for hauling freight trains across the mountains. The electric service has been in operation since 1909 and is at present merely a shuttle service through a tunnel from a yard on one side to a yard on the other, the distance being about 4·5 miles.

Under steam traction trailing loads from 1,400 to 1,500 tons were handled by two Mallets (weighing each 225 tons), assisted by a powerful banking engine. Three electric locomotives, each weighing 103 tons, haul the train including the two Mallets (representing therefore a trailing load of about 2,000 tons) at an average speed of 14 miles per hour as compared with from 9 to 10 under steam. Steam locomotives are, as is well known, very uneconomical on heavy grades, and on this small stretch the saving amounts to 100 dollars per day.



Three-Phase Locomotive in use on the Cascade Tunnel Section of the Great Northern Railway, U.S.A.

Total Weight, 103 *tons; Voltage,* 6,600; *Total Horse-Power Capacity,* 1,700 *H.P. Three of these Locomotives are capable of hauling a train weighing* 2,000 *tons up a grade of* 1 *in* 45 *at a speed of* 15 *miles per hour.*

Another subject of considerable interest is that of shunting heavy goods traffic in yards and sidings by electric locomotives. It is a question of much importance, but has so far received little attention in this country. With electric traction a more efficient shunting service can be obtained, because great train weights can be handled in much less time than with steam. Shunting with steam locomotives is very unsatisfactory, as the engine stands idle for a very considerable part of its time, consuming water and coal all the while. The extent to which a saving in this respect can be made does not seem to be generally appreciated. Mr. Murray, who carried out several tests with steam shunting locomotives on the New York and New Haven Railway, obtained the following highly instructive figures :—

Total time of Throttle Open, 36·7 per cent.
Total time of Engine in Motion, 62·5 per cent.
Total time of Engine Standing, 37·5 per cent.

It can easily be proved to be a sound commercial policy to substitute electric in place of steam locomotives for shunting purposes, especially in cases where electric traction is already in operation for other train services. Mr. Murray also indicated that his tests demonstrate that in shunting yards speeds can be greatly increased by the use of an electric locomotive of very much less engine-capacity than is necessary with the steam engine. It has already been shown that the saving in coal per horse-power-hour at the rim of the drivers amounts to 50 per cent. with passenger electric locomotives, but in the case of shunting locomotives it is about 80 per cent.

An electrically operated shunting service is now satisfactorily worked at the Harlem River Yard, outside New York (see *Electrician*, Sept. 12th, 1913, p. 926).

CHAPTER IX.

Among many other advantages of electric traction may be mentioned the following :—

> The abolition of steam enables sweeping improvements to be made along the route, in the terminal stations and in yards. It allows of the construction of new thoroughfares, arcades, and the building of commercial structures immediately above the electrified railway. Examples of this can be seen at High Street, Kensington, and the Liverpool Street Station of the Metropolitan Railway, where an arcade connecting Broad Street with Liverpool Street is built directly over the railway—a scheme which would have been impossible if steam working had been retained. These commercial advantages enhance the value of railway property and form an important asset.

The great and increasing competition of motor buses and trams has severely affected the suburban traffic of many railways, but this has been met with some measure of success by reductions in fares and rates for season tickets.

It would appear that some companies are at present undecided whether to relinquish the idea of retaining a portion of suburban traffic or contrive to provide for it by electrification. In the London Traffic Report (1911), page 69, the following paragraph appears :—

> There appears to be some difference of opinion among the companies as to whether it is better to keep and foster their suburban traffic or let it go and concentrate their energies on the promotion of traffic further afield. The two objects are not necessarily incompatible and it might not be found impossible to achieve both.

One must, however, not lose sight of the fact that an enormous amount of capital has been spent on the suburban railways round London, and the cost of these lines is, in proportion, much higher than that of the main lines. It does not seem at present an economic proposition to leave the capital thus spent unproductive, and the cost of electrification will only represent a very small proportion of the total capital already expended; consequently electrification has much to commend it, since it enormously increases the earning power of such lines. Furthermore, by providing a more frequent and speedy service throughout the day it will greatly foster the all-day traffic—a much more remunerative item than the rush traffic, which is usually the least profitable part of the business. The fixed capital charges fall upon the idle hours as well as upon the busy, and for every minute that a railway is non-active there is a loss of money. Railway economics point to the advantages of increasing the volume of traffic in every possible way, so that the proportion of idle hours is reduced, and this reduction can only be economically obtained by the adoption of electric traction.

The principal consideration which led to the electrification of the Inner Circle was the increased capacity for traffic which electric traction affords. The only hope of obtaining a return on the heavy capital cost of such lines as the Metropolitan and District lay in utilizing their capacity to the fullest possible extent, and this could only be done by the adoption of electric traction. What might have happened to the Metropolitan and District Railways had steam working been continued may be inferred from the experience of the North London Railway, which operates under somewhat similar conditions.

The natural reluctance of railway companies to spend large sums of money keeps electric traction in the background, although abundant figures have been obtained to show that, under certain conditions, a considerable saving in fuel, engine repairs and other expenses would undoubtedly follow electrification It must be understood, however, that the conversion of a steam railway to electrical working should be undertaken with a view to increase receipts—not with the idea of keeping down expenses.

We can easily compare gross earnings, but, for reasons already given, a comparison of operating expenses per train mile before and after electrification is difficult, as the inauguration of electric traction usually brings with it an alteration in speed and the size and type of trains. Under favourable conditions there may be a saving in operating expenses large enough to pay interest and other fixed charges on the additional capital invested and still leave an appreciable margin. Such conditions might obtain on busy sections of a main line where the suburban area is already electrified and where the additional capital cost of electrification would not be great. In such an instance there would be a large saving in fuel consumption, as the need to increase the speed of the trains, as is the case with suburban traffic, would not arise.

The dual operation of steam and electric trains in the same area will rarely prove profitable, as a large proportion of the expenses incidental to both systems are retained, without receiving the full benefits of either system. To ensure the fullest economy there should be but one system of motive power, and if electric traction be introduced it should extend to goods trains as well as to passenger trains, and also to shunting yards, etc.

In considering the electrification of a railway, emphasis is usually placed upon the extra expenditure involved in building generating stations and substations, providing new rolling stock, etc., but other items of really more importance are sometimes ignored. It is not sufficiently realized that such conversion practically doubles the carrying capacity of the railway without laying down additional lines or enlarging stations. We have already seen how multiple unit motor-cars increase the carrying capacity of terminal stations owing to absence of shunting movements.

Terminal traffic in large cities is, as a rule, very dense, while the number of tracks converging upon the termini limits the capacity of these stations. Real estate in the immediate neighbourhood is very dear, so that the cost of increasing the terminal capacity by expansion is enormous, and far in excess of the entire cost of electrification of the system.

The railways that have adopted electric traction at their termini have reduced traffic congestion, while the number of trains handled has been greatly increased. Mr. Wilgus has stated that the capacity of the New York Central Station has been very much increased by the introduction of electric traction. The chairman of the South Eastern and Chatham stated, when the question of electrifying the North Kent lines was laid before the board, that he did not think the operation would pay unless it became necessary to increase the accommodation of either Cannon Street or Charing Cross Stations, when it might be wise to electrify in preference to buying land and widening the stations (see London Traffic Report (1911) page 69).

As already stated, the considerations upon which success or failure turns in connection with electrification are perfectly well known. The capital costs, the operating expenses and probable commercial results can be closely estimated; so that the railway companies themselves, who alone are familiar with the conditions of their respective systems, must decide whether it is more to their advantage to accept the loss of short-distance traffic or to incur the additional outlay for electrification and seek to preserve the traffic with every possibility also of obtaining a larger volume than ever.

It is now a very general custom for business people to live as far away as possible from big city centres, and the railways must provide for these changed conditions. Passengers reckon distance in "minutes," and will avail themselves of any opportunity to travel as far as they can in a given time. The Royal Commission on London Traffic reported in 1905 :—

> It is, we think, evident that the introduction of electric traction will lead to a great improvement of suburban and urban railway facilities in London ; the speed of all trains worked by electricity, especially those which stop at many stations, will show substantial increase over the speed of steam trains. It will, we believe, also be found that electric traction, apart from its own advantages, will enable railway companies to increase the number of trains working in and out of the terminal stations and thereby add largely to the facilities afforded for suburban traffic. We hope therefore that there may be no great delay before the railway companies serving London adopt electric traction for the working of their train services.

The London Traffic Branch of the Board of Trade in 1910 reported :—

> The electrification of suburban railways would confer great benefits upon the public. It would increase the facilities for travelling, bringing the suburbs closer to the centres of London in point of time and stimulate the outer movement of the population.

Mr. Aspinall, concluding his address to the Institution of Mechanical Engineers, said :—

> Experience has convinced me that there are a number of suburban lines around our great cities, and especially near London, which can be electrified with advantage to the public and to the railway companies, although we must wait awhile before dealing with long distance travelling.

Summarized, the present state of electric traction is as follows :—

> When compared with steam it shows to its greatest advantage in suburban passenger service, owing to the high acceleration which can be obtained. The advantages of high acceleration are: increased schedule speeds of local trains from 30 to 50 per cent., and, without increasing the number of tracks

or the terminal accommodation, a much more frequent service of trains without a proportional increase in operating expenses. In times of light traffic "small" trains can be used, the energy in such cases being practically in proportion to the number of coaches run. Electric traction does not diminish the total working expenses, but it increases the earning power by enabling a larger volume of traffic to be handled. The large power houses near city centres necessitated by electrification for suburban passenger traffic can be gradually enlarged to supply other sections of the railway (or other railways near at hand) until finally the whole area is electrified.

Although, for reasons already given, no universal electrification of railways is to be expected at present, we can confidently look forward to great strides being made in this direction during the next few years. There is, for the time being, some conservatism amongst railway companies, which is chiefly due to the large amount of capital that would have to be sunk in electrification schemes, but there are signs that their attitude is undergoing a change. The application, however, of electric traction to heavy railway service will be governed by other and more important considerations than its mere relative costs as a motive power under similar conditions. This is well illustrated in the development of the tramcar, where the commercial value of higher speeds and increased carrying capacity is so great that the cost of electric traction versus that of animal power has out-grown all comparison. There is little doubt that similar results will be obtained in the corresponding development of electric traction in heavy railway service. The time will come when railways will be compelled to adopt electric traction, not only on account of getting a larger tractive effort per train, but also on account of the continued rise in cost of fuel.

The extended use of motor 'buses and motor lorries may affect railways to a degree which as yet cannot be foreseen; already the transport by road of the higher-rated and more profitably-carried goods traffic has assumed large proportions.

Railway companies will have to face these new conditions and change their methods accordingly. Electrification is the most powerful weapon with which to fight the new competition, and we can confidently look forward to large extensions in the near future of electrical working, both on suburban and main lines.